Project Plan

Earth and Space Sciences (ESS) Project

UPN 625-20

June 16, 2000

High Performance Computing and Communications (HPCC) Program
National Aeronautics and Space Administration

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Foreword

This document contains the Project Plan for the NASA HPCC Earth and Space Sciences (ESS) Project. It supercedes and replaces in total the July 1998 *ESS Level-2 Project Plan*. This ESS Project Plan is substantively different from the prior plan because of the issuance on April 3, 1998 of the document *NASA Program and Project Management Processes and Requirements* (NPG: 7120.5A) that establishes the management system for processes, requirements, and responsibilities for implementing NPD 7120.4A, Program/Project Management. This management system governs the formulation, approval, implementation, and evaluation of all Agency programs and projects established to Provide Aerospace Products and Capabilities (PAPAC). This ESS Project Plan, is fully compliant with NPG 7120.5A.

The July 1998 *ESS Level-2 Project Plan* placed most of its emphasis on 'what' the ESS Project was doing, while this new ESS Project Plan in conformance with NPG 7120.5A places most of its emphasis on the 'process' by which ESS manages its work.

Copies of the July 1998 *ESS Level-2 Project Plan* are available from the ESS Project Manager. The document NPG: 7120.5A can be downloaded from a NASA web site at: http://nodis.hq.nasa.gov/Library/Directives/NASA-WIDE/Procedures/Program_Formulation/N_PG_7120_5A.html

PROJECT PLAN
EARTH AND SPACE SCIENCES (ESS) PROJECT

1. INTRODUCTION

1.1 Introduction
This document is the Project Plan for the NASA High Performance Computing and Communications (HPCC) Program's Earth and Space Sciences (ESS) Project. It is consistent with the HPCC Program Plan and the President's FY 2001 budget. It is consistent with the normal procedures used by the Earth Science Enterprise for a Technology Project governed by NPG 7120.5A. This plan covers the time period FY 2000-2004 and is the controlling document that defines the top-level technical and management structure of the ESS Project. It establishes:
- Project requirements
- Project objectives and performance goals
- The management organizations responsible for the project throughout its life cycle
- Project resources, schedules, and controls

The ESS Project, described in this document, accelerates the development of high-performance computing and computer communications technologies to meet the needs of the U.S. Earth and space science communities. It also accelerates the distribution of these technologies to a broader community including the American public. The technologies developed under this plan help maintain U.S. technical and economic leadership in the international arena of high-performance computing. Extensive information about the ESS Project is available on its Web site at: http://esdcd.gsfc.nasa.gov/ESS/

1.2 Background
NASA's HPCC Program is an integral part of the Federal program in Computing, Information, and Communications (CIC) that is summarized in the HPCC Program Plan. The goals of the NASA Program are:

1) to accelerate the development, application, and transfer of high-performance computing and computer communications technologies to meet the engineering and science needs of the U.S. aerospace, Earth and space science, spaceborne research, and education communities and
2) to accelerate the distribution of these technologies to the American public.

The NASA HPCC Program is structured to contribute to the broad Federal effort while addressing agency-specific challenges that are beyond projected near-term computing capabilities. The Program is organized into five projects. Three are computing projects: the Computational Aerospace Sciences (CAS) Project, the ESS Project, and the Remote Exploration and Experimentation (REE) Project. The fourth is a communication project, the NASA Research and Education Network (NREN) Project, and the fifth is a focused technology project, the Learning Technologies Project (LTP). Each project is managed by a Project Manager located at one of the NASA centers. The Center responsible for the management of CAS, NREN, and LTP is the Ames Research Center; for ESS it is the Goddard Space Flight Center; and for REE it is the Jet Propulsion Laboratory.

NASA selects high-end computational challenges in the domains of CAS, ESS, REE, and NREN on the basis of their potential direct impact to NASA, their national importance, and the technical challenge they give the NASA HPCC Program. The goals addressed in the LTP Project were chosen for their relevance to NASA's science, education, and outreach efforts.

The science and engineering requirements inherent in the selected NASA applications require at least three orders of magnitude improvement in high-performance computing and networking capabilities over the capabilities that existed at the beginning of the program in FY 1992. Of equal importance, significant advances in interoperability, portability, reliability, resource management, and usability are essential to the pervasive and effective application of increased computational and communication performance to NASA's goals. NASA's requirements in these areas are beyond the planning horizons of the commercial sector. NASA must develop new approaches and technologies and demonstrate their feasibility before the commercial sector can move aggressively into these areas and eventually meet NASA's requirements.

The NASA HPCC research and development approach capitalizes on teams of computational scientists, computer scientists, and discipline scientists. These teams are composed of researchers from NASA centers, research institutes and centers of excellence, industry, and universities. Close coordination and interaction are being maintained with other Federal agencies. Whenever feasible, collaborative efforts are being undertaken.

1.3 History

ESS was included as a charter component of the NASA HPCC Program, beginning with planning in FY 1990, study level funding in FY 1991, and new start funding in FY 1992. Since the beginning of the Project, GSFC has served as the Project lead Center and JPL as the associate Center. ESS issued a NASA Research Announcement (NRA) in FY 1992 and a Cooperative Agreement Notice (CAN) in FY 1995 that resulted in selection of Round-1 Grand Challenge Teams funded in FY 1993-96 and Round-2 Grand Challenge Teams funded in FY 1996-2000. Round-1 and -2 are described in Appendix B. This Project Plan focuses on the ESS Round-3 activities.

1.4 Vision, Goals

The goal of the ESS Project is *to demonstrate the power of high-end, scalable, and cost-effective computing environments to further our understanding and ability to predict the dynamic interaction of physical, chemical, and biological processes affecting the Earth, the solar-terrestrial environment, and the universe.*

ESS shares its vision for addressing this goal with that stated by the President's Information Technology Advisory Committee (PITAC) in its February 1999 report to President Clinton [http://www.ccic.gov/ac/report/], "We stand at the dawn of a new century, a century where leadership in information technology may well be economically and militarily decisive. To meet this 21st century challenge, we believe we must diversify the modes of research supported by the Federal Government. Computer science and information technology are collaborative research fields. Hence, special emphasis should be placed on involving and supporting researchers at many institutions in large-scale research projects that can explore technologies farther into the future with teams of researchers that may be interdisciplinary and multi-institutional."

The ESS Project strives to enable the NASA science Enterprises and their field centers to meet increasing mission requirements more effectively and efficiently. Guided by the Strategic Plans of the Earth and Space Science Enterprises as well as the Life & Microgravity components in the Strategic Plan of the Human Exploration and Development of Space Enterprise, ESS research increases NASA's capability to produce, analyze, understand, and access its science and mission data while reducing the required investment in money, time, and human resources.

A primary ESS objective is to provide the necessary scalable computational technologies and software tools to further the development of a suite of multidisciplinary models, simulations, and analyses of data products by the NASA science community toward the goal of scalable global simulations coupling many disciplines and to the simulation of complex multiple-scale problems associated with space science. Many of these challenges require the integration and execution of multiple advanced disciplinary models as single multidisciplinary applications. Examples of these include coupled oceanic-atmospheric-biospheric interactions, 3-D simulations of the chemically perturbed atmosphere, solid Earth modeling, solar flare modeling, and space weather modeling. Others are concerned with analysis and assimilation into models of massive data sets taken by spaceborne sensors in the areas of global warming and ozone depletion on Earth and planetary science and astronomy. High-resolution, multidisciplinary models are important for their predictive value and for their ability to extrapolate beyond our ability to measure and observe systems directly. For example, if the time scale of interest is on the order of 100 years, systems must be simulated for thousands of years. Learning what the important interactions are, what their time scales are, and what controls exist in the system are important needs of the emerging Earth systems science. These problems are significant in that they have both social and political implications in our society. The science requirements inherent in the NASA high-end computational challenge applications necessitate software interoperability, "capability[1]" computing performance at the teraflops level or greater, and networking capability in the gigabit per second range.

The advanced semiconductor and fiber optic technologies that are driving ground-based computing and communications advances are also migrating into flight instrument sensors, providing improved spatial and spectral resolution and resulting in higher data rates to the ground. Analysis of the data produced by these sensors requires data retrieval algorithms that may scale with the square of the data resolution. Ground-based computational systems must process and analyze this data at rates that meet or exceed the rates at which they reach the ground. The volume of data to be obtained from next-generation spaceborne sensors will be so great that current and next generation computing systems will be inadequate for the required modeling, data assimilation, and analysis tasks. Data from many sensor systems will be collected at frequent intervals over many years, stressing mass storage systems and enabling reprocessing projects that can again dramatically increase the throughput requirements on computing systems and their data I/O capabilities.

As a direct result of the initial phase of the HPCC Program, high-performance scientific codes have emerged as powerful tools for performing important work for NASA. These highly capable scalable codes have exposed new issues that are as important as performance: code interoperability, portability of applications among the variety of high-performance architectures, and management of the complexity of resulting coupled models. It has become evident that additional performance, though necessary, is not sufficient to make a code useful for support of NASA research and missions. The cost to adapt existing high-performance research codes to function with suites of NASA research or production codes for evaluation and eventual adoption and use may be prohibitively high. This is because code interoperability, which often exists among code components within specific research groups, rarely exists between these groups and there are many such groups. In some cases, several Agencies such as NASA, NSF, DOE, and DOD fund multiple research groups within a modeling community, all researching advanced models, but these models lack the ability to interoperate. This situation is not a significant issue when the primary products of the research groups are research findings shared through scientific papers. However, with the emergence of powerful modeling and analysis codes as key tools of NASA science and mission support, preparation of these codes for ease of incorporation and use by NASA has become extremely important.

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[1] capability computing: Access to a significant collection of computing resources in a coordinated fashion within a finite window of time. Requires the utilization of over half of the system's CPU, memory, disk, and/or I/O resources to support individual applications. In the extreme, capability jobs are so memory or CPU-intensive that the dedication of a large resource for days or weeks is required. May involve interactive analysis and visualization of data that is too large to be moved to or displayed on the users' desktops.

Since the inception of the NASA HPCC Program, substantial progress has been made towards enabling high-end computational challenges to run at sustained teraflops levels on highly parallel computers. For instance, by early 1998 ESS had demonstrated several major science codes executing at 100 gigaflops sustained, a rate roughly 200 times faster than what was possible when HPCC began in 1992. By FY 2002 some vendors may produce systems able to sustain 1,000 gigaflops on ESS science codes. These future systems, however, will continue to require high-end computational challenge Investigators to develop efficient and effective parallel algorithms for the new architectures and require the computer science community to develop software tools and computational libraries to assist the Investigators. The cost of hardware needed to deliver a large fraction of a teraflops of computing is expected to drop dramatically by FY 2004, especially in cases when this work can be performed by clusters of commodity processors. The software challenges, however, will be greater for users of these systems as they deal with high interprocessor latencies that come as a penalty with the much reduced price.

1.5 Overall Approach/Timeframe

ESS is preparing to issue a Cooperative Agreement Notice (CAN) in FY 2000 to select Round-3 Investigations for funding in FY 2000-04. This CAN is described in Section 6.2 below. The Round-3 Teams will serve as leading-edge developers of high-performance applications codes and aggressive users of leading-edge scalable Testbed systems and their software environments. They are to improve important application codes and expand their interoperability with other related codes within self-defined multidisciplinary scientific communities. They are to make their improved application codes and associated interoperability software and standards freely available on the Web in source form. Round-3 Teams will contribute significantly to the research synergism of the ESS Project that also includes:

- University and private sector, as well as GSFC and JPL, computer and computational scientists developing high-performance computational plug-in application codes in support of various frameworks represented by Round-3 Investigations;
- ESS evaluation staff characterizing Team application codes and carrying out performance and scaling measurements on the Testbeds;
- A Teraflops Scalable Testbed along with application performance optimization support staff assisting Teams to achieve code improvement milestones [see descriptions in section 10.1 Implementation Approach, and Table 11-2 Teraflops Scalable Testbed acquisition summary];
- A Commodity Based Testbed along with system software developers and applications support staff evolving and supporting high-end clusters of PCs for use and evaluation by Teams;
- Guest Investigator allocations of Testbed time for testing by the broader Earth and space science community;
- NASA software engineers facilitating development of an Earth System Modeling framework for interoperability of application codes;
- NASA staff developing applications middleware, high-end visualization, and mass storage technologies;
- ESS and NREN staff developing and applying wide area networking technologies;
- The Scientific Visualization Studio at GSFC developing visualization products for Investigator Teams; and
- Support and training of HPC doctoral students and post-doctoral scholars.
- Collaboration with other NASA HPCC projects in areas such as frameworks, system software, tools, and testbeds.

2. OBJECTIVES

The NASA HPCC goals listed in Section 1.2 are supported by specific objectives listed below. The highest-level objective is to enable the use of high-performance computing and communication technologies to improve the effectiveness of the HPCC Program's customers. To meet the customer impact objective, it is necessary for ESS to achieve specific improvement objectives in performance, interoperability, portability and usability. Performance goals and performance indicators are listed below for each objective. They match with those assigned to ESS in the HPCC Program Plan. Performance goals are expressed in an objective, quantifiable, and measurable form. Performance indicators suggest characteristics of the ongoing work that would indicate that work towards meeting the performance goals is underway. The performance goals appear in Section 7 as metrics for Program and Project milestones.

2.1 Customer Impact Objective

Infuse HPCCP technologies into mission critical stakeholder Enterprise/Office processes, document discernible improvements in the stakeholders' processes and, if possible, document discernible improvements in the final products as a result of the use of HPCC technologies.

Performance Goals

Document 25 scientific research groups using applications supporting NASA science objectives operating at 10X improvement using negotiated science metrics over initial ESS Round-3 application baseline and 40% interoperating with stable Earth and space science frameworks impacting at least 5 scientific communities (2 or more applications per framework; 3 applications interoperating within a stable Earth System Modeling Framework). [ESS milestone 1-17]

Demonstrate 50 gigaflops sustained applications performance at $250K for 50% of Round-3 Investigations. [ESS milestone 2-7]

Performance Indicators

- Availability of computational tools
- Comparison of model output to satellite sensor data sets
- Comparison of integrated coupled model output to satellite sensor data sets
- Incorporation of HPCC technology into NASA spacecraft and aircraft platforms

2.2 Computational and Communication Performance Objective

Dramatically increase the computer and communication performance available for use in meeting NASA mission requirements.

Performance is defined as the rate at which a computer performs operations, or a network transfers data, or a storage system stores/retrieves data, or an application and underlying computational system completes a task.

Performance Goal

Demonstrate the effective use on Earth and space sciences challenges of computational or communications systems delivering:

- 250 gigaflops sustained on applications, ground based. [ESS milestone 2-2]

Demonstrate the effective use on Earth and space sciences applications delivering:
- On a weekly basis, ensembles of 1-year climate forecasts using a 1-degree atmosphere and a 1/3-degree ocean
- Assimilation of atmospheric data at 1/2-degree resolution at a rate of 30 days per day

Performance Indicators
- Capability computing testbeds
- Development of low cost platforms
- Performance analysis and monitoring tools
- Reduction of requirements through improved algorithms
- Implementation of new networking technologies and capabilities
- Enabling usage of revolutionary application across Next Generation Internet

2.3 Interoperability Objective

Dramatically increase the interoperability of application and system software operating on high-performance computing and communications systems available for use in meeting NASA mission requirements.

Interoperability is defined as the ability of software on multiple machines from multiple vendors to communicate.

Performance Goals
Demonstrate on Earth and space science challenges technologies that enable:
- Interoperation among at least three applications in the Earth System Modeling Framework, and two applications in at least four other Earth and space science frameworks. [ESS milestone 1-17]
- Integration of a new computational simulation, data analysis, or other tool into an interdisciplinary framework in 1 day. [ESS milestone 1-11]

Performance Indicators
- Industry-standard software design and coding practices
- Configuration management and interface agreements

2.4 Portability Objective

Dramatically improve the portability of application software and data to new or reconfigured high-performance computing and communications systems available for use in meeting NASA mission requirements.

Portability is defined as the ease with which a piece of software (or file format) can be "ported," i.e., made to run on a new platform and/or compile with a new compiler.

Performance Goals
Demonstrate on NASA Earth and space sciences challenges technologies that enable:
- Successful execution of a computational simulation, data analysis, communication, and other tools on a new computer, network, storage system, or combination of these resources within 1week. [ESS milestone 1-11]
- Successful execution of a computational simulation, data analysis, communication, and other tools on a compute, network, storage, or combination of these resources within one day of a modification in the software or hardware configuration of these resources. [ESS milestone 1-11]

Performance Indicators
- Use of software engineering techniques
- Software reusability

2.5 Customer Usability Objective
Dramatically improve the usability of high-performance computing and communications tools and techniques available for use in meeting NASA mission requirements.

Usability is characterized as the effectiveness, efficiency, and satisfaction with which users can achieve tasks in the user environment presented by a technology or integrated system of technologies. High usability means a system is: easy to learn and remember; efficient, visually pleasing and easy to use; and quick to recover from errors.

Performance Goals
Demonstrate on NASA Earth and space science challenges technologies that:
- Improve the commodity cluster software environment strategically for the benefit of the ESS community. [ESS milestone 3-13]

Performance Indicators
- Usability testing
- Identification of specific usability requirements
- Development of software modules or systems to enhance usability

3. CUSTOMER DEFINITION AND ADVOCACY
ESS is a crosscutting technology activity striving to enable its customer Enterprises and their Centers to, in turn, more effectively and efficiently deliver products and services to their customers. The principal government customers of ESS are NASA's Earth Science Enterprise, Space Science Enterprise, Human Exploration and Development of Space (HEDS) Enterprise, and government research labs performing scientific research in Earth and space sciences. The principal industry and academic customers of ESS are university labs performing scientific research in Earth and space sciences.

Advocacy for the HPCC Program within NASA is led by the Aerospace Technology (AT) Enterprise, with support from the other three sponsors: the Earth Science and Space Science Enterprises, and the NASA Office of Human Resources and Education. The HPCC Program Executive Committee and the Executive Committee Working Group are the key interfaces to the sponsoring NASA Enterprises. The Aerospace Technology Enterprise serves as the primary liaison for interactions with other Federal agencies and for advocacy with OMB and Congressional representatives.

ESS outsources most of its work to Investigator Teams based at universities and government labs. Teams are competed periodically to adjust the work of the project, refocus NASA Center-based activities, and assure that ESS continues to be responsive to the needs of Enterprise scientific research areas and flight missions. ESS uses the full and open CAN process to select Investigator Teams. The selection process, described in Section 6.2, is run by Headquarters with logistics support from ESS. The scope of the CAN is established by the Strategic Plans of the Earth and Space Science Enterprises, as well as the Life Science & Microgravity components in the Strategic Plan of the Human Exploration and Development of Space Enterprise.

ESS designs its CANs to select highly qualified scientific Teams from the ESS customer community to develop important advanced systems of high-performance software and then, following validation by ESS, deliver them to a broad community via the Web.

ESS forms the selected Investigators into a Science Team, chaired by the ESS Project Scientist. The Science Team functions as a venue for the Teams' Principal Investigators to speak with one voice to the ESS Project, to NASA management, and to the NASA scientific community. The Science Team typically meets twice annually to carry out business and presents scientific results at science symposia at NASA Headquarters for the benefit of Science Program Managers from customer Enterprises. Each Investigator Team publishes extensively, and at the end of their Investigations, the Science Team members together produce a final report of their findings.

Although the software technology developed and demonstrated by ESS involves full-scale computing and communication systems, ESS does not purchase such systems for its sole use and does not operate such systems as production or operational capabilities, which is the responsibility of the ESS customer Enterprises and CoSMO. ESS does arrange for access to and cost-share full-scale systems with other NASA projects or computer system vendors. ESS works closely with CoSMO to assure that knowledge gained through ESS research activities is transferred to the production and operational computing environment.

Workshops and informal communications are utilized to maintain an interface with large cross-sections of the customer bases. ESS annually holds the NASA Summer School for High Performance Computational Earth and Space Sciences to help train the next generation of computational physicists.

4. PROJECT AUTHORITY

The overall authority for the ESS Project is established by the HPCC Program, which is in turn established by the NASA Headquarters Program Management Council (PMC). The HPCC Program Commitment Agreement (PCA) represents the Agency-level agreement for the implementation of the HPCC Program and its projects. Although three Enterprises and the NASA Office of Human Resources and Education fund the program, the overall management of HPCC is formally within the Aerospace Technology Enterprise and is the responsibility of the HPCC Program Office at the NASA Ames Research Center.

The Goddard Space Flight Center (GSFC) is designated lead Center for the ESS Project. GSFC has ESS Project management authority and responsibility. The Jet Propulsion Laboratory (JPL) supports the ESS Project as an associate Center.

5. MANAGEMENT

5.1 Organization

GSFC is the lead Center for ESS, and JPL is the associate Center. The ESS Project is managed by the ESS Project Manager, who is appointed by and reports directly to the Chief of the Earth and Space Data Computing Division at GSFC. The Project Manager also reports programmatically to the HPCC Program Manager at ARC, the HPCC lead center. The NASA Office of Aerospace Technology is the NASA Headquarters focal point for coordinating the Program's Headquarters-level approvals, reviews, and customer advocacy. The interests of the Earth Science and Space Science Enterprises are represented by the respective Associate Administrators on the HPCC Executive Committee and by their designated representatives on the HPCC Executive Committee Working Group. The HPCC Program and ESS Project receive strategic guidance and direction from these bodies in the form of program objectives, requirements, and metrics. Charters for the Executive Committee and its Working Group define their processes and products.

The ESS Project Manager directs and controls the day-to-day activities necessary to accomplish project goals and ensure customer satisfaction. The ESS Project Manager is assisted by a management team consisting of an Associate Project Manager at JPL, four Deputy Project Managers, a Project Scientist, a Project Computational Scientist, and a Lead for Evaluation. The ESS management team seeks to arrive at a consensus view of direction and resource utilization for the ESS Project as a whole, and hence speak with one voice for the interests of the Project. Figure 5.1 shows the management structure of the ESS Project.

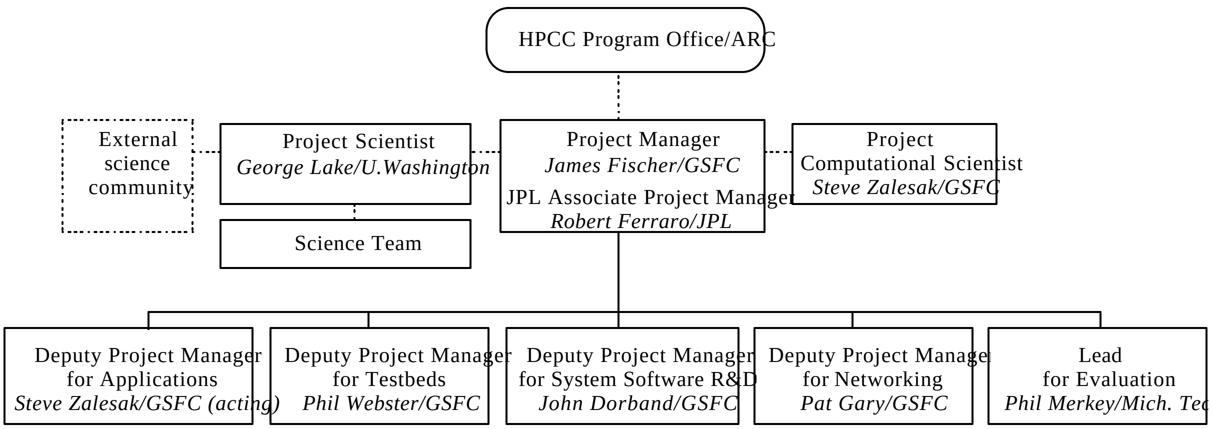

Figure 5-1: Management Structure of the ESS Project

ESS participates in three Program Office sponsored cross-cutting integration management teams chartered in the areas of applications, system software, and testbed research to review and recommend actions to improve the effectiveness of HPCC development, prototyping, and infusion into the customers' processes. Specific issues being addressed are greater cross-Project sharing of application techniques and algorithms, a concerted effort towards developing a technical legacy to support high-performance, interoperable, and portable applications, and the best use of all testbed resources to meet NASA's aerospace, Earth and space sciences, and education mission requirements. Integration Management Team processes and products are defined in the Team Charters.

5.2 Responsibilities

5.2.1 Project Manager

The overall management of the ESS Project is the responsibility of the ESS Project Manager who is appointed by the GSFC Center Director from within the Earth and Space Data Computing Division at GSFC. The ESS Project Manager also reports to the HPCC Program Manager at ARC. The specific responsibilities are:

(a) Provide overall management of ESS as a multicenter Project, including cost, schedule, and technical performance.

(b) Develop, update, and maintain the ESS Project Plan, including the definition and negotiation of resource, schedule, and deliverable commitments, in cooperation with functional managers in the participating and sponsoring organizations.

(c) Manage the ESS budget in line with Agency financial metrics.

(d) Appoint the Deputy Project Managers, the Project Scientist, the Project Computational Scientist, and the Lead for Evaluation; define and interpret task area responsibilities and statements of work; and direct and coordinate their efforts.

(e) Coordinate ESS activities with those of the other NASA HPCC Projects and through the Federal HPCC Program coordinate ESS activities with those of related programs in other Government agencies.

(f) Direct and control the day-to-day activities necessary to accomplish the goals and objectives of the Project and to ensure customer satisfaction.

(g) Submit Project reports and prepare and present Project reviews and technical advocacy materials.

(h) Report ESS Project performance, as well as management and financial status, including contracts, to the HPCC Program Manager. Prepare an accomplishments summary suitable for inclusion in the HPCC Annual Report.

(i) Maintain a current Project-level Web site linked to the HPCC Program Web site.

(j) Comply with applicable Federal law, regulations, Executive Orders, and Agency Directives.

5.2.2 Associate Project Manager

The ESS Associate Project Manager resides at JPL and is appointed by the Director of the Technology and Applications Programs Directorate at JPL, from that Directorate. The specific responsibilities are:

(a) Assist the Project Manager to develop, update, and maintain the ESS Project Plan, including the definition and negotiation of resource, schedule, and deliverable commitments, in cooperation with functional managers in the participating and sponsoring organizations.

(b) Manage the ESS/JPL budget in line with Agency financial metrics.

(c) Coordinate, manage, direct and control the day-to-day Project Work Breakdown Structure (WBS) activities at JPL necessary to accomplish the goals and objectives of the Project and to ensure customer satisfaction.

(d) Track and report ESS/JPL Project performance and status.

(e) Prepare, submit, and present reports, reviews, and briefings on Project implementation status to the Project Manager and to indicated senior managers at their respective Centers.

(f) Comply with applicable Federal law, regulations, Executive Orders, and Agency Directives.

5.2.3 Deputy Project Managers

The Deputy Project Managers are appointed by the Project Manager and assist the Project Manager in the day-to-day operation of the Project. Four key Project areas are each led by a Deputy Project Manager who is responsible for the day-to-day activities within that area.

5.2.3.1 Deputy Project Manager for Applications

(a) Oversee the solicitation process leading to selection of Science Investigations.

(b) Oversee ESS provided computational technique collaborations with Science Investigations.

(c) Oversee CAN Investigator milestone validation.

(d) Oversee Testbed allocation process for Guest Investigators.

(e) Oversee computational technique collaboration and applications support for Guest Investigators.

(f) Oversee ESS Investigator budget.

5.2.3.2 Deputy Project Manager for Testbeds

(a) Oversee or participate in the solicitation process leading to selection of the primary ESS Testbed(s). Facilitate system augmentations.

(b) Oversee resource allocations, user accounts, user environment, and user system support.

(c) Oversee ESS Testbed budget.

5.2.3.3 Deputy Project Manager for System Software R&D

(a) Evolve the ESS system software R&D program as a key contributor to the ESS Project and the Federal HPCC Program.

5.2.3.4 Deputy Project Manager for Networking

(a) Represent ESS requirements to the NREN Project Manager to facilitate Investigator access to ESS Testbeds via NREN.

(b) Provide the local network connectivity between ESS/GSFC Testbeds and NREN systems as well as the other wide area networks of significance to ESS.

(c) Demonstrate high-end networking technologies in the context of Science Investigations.

5.2.4 Project Scientist

The Project Scientist was appointed by the Project Manager in Round-2 but will be elected by the Science Team PIs in Round-3. The specific responsibilities are:

(a) Chair the ESS Science Team and assure that it functions as a team.

(b) Represent the views and interests of the ESS Investigators to the Project Manager and to Headquarters Enterprise management and program scientists.

(c) Identify scientific discoveries made by ESS Investigators.

(d) Promote awareness of the value of the science produced or enabled by ESS to the scientific community and the public.

(e) Advocate technology goals supportive of ESS in Enterprise strategic plans.

5.2.5 Project Computational Scientist

The Project Computational Scientist is appointed by the Project Manager. The specific responsibilities are:

(a) Support the solicitation process leading to selection of Science Investigations.

(b) Identify computational science innovations made by ESS Investigators; communicate the same to the Project Scientist and Project Manager.

(c) Promote awareness of the value of the computational science produced or enabled by ESS to the scientific community.

(d) Organize and advocate participation in seminars, workshops, and training for exchange of technical knowledge developed by the Project.

5.2.6 Lead for Evaluation

The Lead for Evaluation is appointed by the Project Manager. The specific responsibilities are:

(a) Lead effort to characterize ESS Investigator codes and predict their characteristics to achieve desired science capability.

(b) Publish characterization data and projections for use by next-generation computer architects.

5.3 Special Boards and Committees

A key aspect of the ESS approach is the periodic issuance of CANs that adjust the work of the Project and assure that it continues to be responsive to the customer Enterprises. These CANs result in selection of new groups of Science Investigations. The CAN selection process is run by NASA Headquarters with support from ESS and utilizes a Peer Review Committee and a Selection Committee in key evaluation and decision making capacities. This process, described in Section 6.2, occurs every 3 to 4 years.

A source of science community input is the ESS Science Team, described above in Section 3. It is composed of the ESS Science Investigators, chaired by the ESS Project Scientist, and performs customer advocacy on behalf of ESS and the Enterprises by functioning as a venue for the Investigator Teams to speak with one voice to the ESS Project, NASA management, and the NASA scientific community.

5.4 Management Support Systems

ARC is the lead center for not only the HPCC Program but also the Consolidated Supercomputing Management Office (CoSMO), under whose umbrella the NASA Center for Computational Sciences (NCCS) at GSFC operates. ESS works closely with the HPCC Program Office and CoSMO to assure that the research results of ESS transition into production and operational use by CoSMO; primarily on the NCCS production floor.

6. TECHNICAL SUMMARY

The goal of the ESS Round-3 CAN (FY00-04) is to enable production-ready, high-performance Earth and space science computational applications that analyze or interpret NASA Enterprise observational mission data. Advanced software technology is a primary product. This software is developed, used, and evaluated by scientific researchers addressing the high-end computational challenges of NASA science. This pioneering work reduces the risks assumed by subsequent NASA scientific researchers when adopting high-performance computing technologies.

6.1 Project Requirements

The approach taken by ESS is derived from requirements placed on it from several sources. ESS requirements are introduced in Section 1.4 above. They evolve over time.

1) Near-range (FY 2000-02) requirements of selected ESS Science Investigator Teams representing the benefiting NASA science community include:

- Improve software engineering environments to manage the complexity of evolving high-performance modeling and analysis software systems.
- Bring about interoperability of high-performance code components within and among related research groups.

- Design software for rapid portability and performance optimization of applications among the variety of high-performance architectures.
- Improve key high-performance codes in units of quality valued by the NASA science community or flight projects.
- Achieve interoperability of application components and high performance simultaneously.
- Provide key middleware software components compatible with the software interoperability standards.
- Provide more capable Testbed systems and environments to carry out the research that addresses the above requirements. Figure B-1 in Appendix B summarizes representative system requirements stated by Round-2 Teams. The medium and preferred resolution requirements are expected to be typical of those of Round-3 Teams.
- Provide more cost-effective Testbed systems to support Investigator research.
- Provide visualization tools capable of handling the data volumes associated with teraflops systems and that are accessible from remote locations.

2) Mid-range (FY 2002-10) requirements of the sponsoring Enterprises at NASA Headquarters include:

- Address fundamental problems in science with potentially broad economic, political, and/or scientific impact.
- Address significant elements of the NASA Enterprises' Strategic Plans.
- Incorporate the use of NASA data to understand Earth or space science phenomena.
- Have broad impact on the NASA science community.

6.2 Technical Approach

The technical plan for ESS Round-3 (FY 2000-04) is defined by the ESS Project milestones listed in Section 7. It is organized into three major efforts focused on *high-end computational challenges, computing testbeds, and system software.*

ESS *high-end computational challenges* (hereafter referred to as Science Investigations, or Investigations) are selected because of their scientific importance, ability to drive high-performance end-to-end computational technology development, and diverse workloads representative of what might be found as part of an Earth and space science computing facility 3 to 5 years out. High-end computational challenge research focuses on areas critical to NASA science as described in Section 1.4 above.

Round-3 is designed to have broad impact in the scientific community. Investigations are sought whose code products will be used by other groups, especially through an identifiable provider/customer relationship. Customers of Round-3 technology include NASA scientific research programs and flight missions that require mature high-performance codes for use in production and operational computing environments. Investigator Teams will be asked to advance the performance of proposed specific application codes and expand their interoperability with other related codes within self-defined multidisciplinary scientific communities. Development of an Earth System Modeling Framework (ESMF) will be a high priority. Application performance optimization and user support is provided to the Investigators. Desired outcomes include fostering reusability among software components and portability among high-end computing architectures; reduction in the time required to modify research application codes; structuring of systems for better management of evolving codes; and enabling of software exchange between major centers of research. Developed software is delivered to specific communities as planned in customer milestones and to the broad community via the National HPCC Software Exchange (described in Section 12.2).

ESS Round-3 Investigations will be selected during FY 2000 from proposals submitted in response to NASA Cooperative Agreement Notice (CAN) #23456-253 titled "Increasing Interoperability and Performance of Grand Challenge Applications in the Earth and Space Sciences." This CAN is available on the ESS Web site at http://esdcd.gsfc.nasa.gov/ESS/. The selection process, diagrammed in Figure 6-1, takes place under the supervision of the Headquarters Selection Official. It involves a full peer review run by the Peer Review Committee, chaired by a Headquarters official and staffed by officials from offices at Headquarters and from within the HPCC Program. The peer review includes 'mail reviews' [steps 1-2] and discipline panels [steps 4-5] that rate proposals within science thrust areas. The product of the peer review [step 6] is then handed up to the Headquarters Selection Committee [step 7], whose voting membership is composed entirely of Headquarters officials. This committee merges the top ranked proposals from all the disciplines into a single ranked list and presents it with recommendations to the Selection Official who selects proposals for negotiation by the Project.

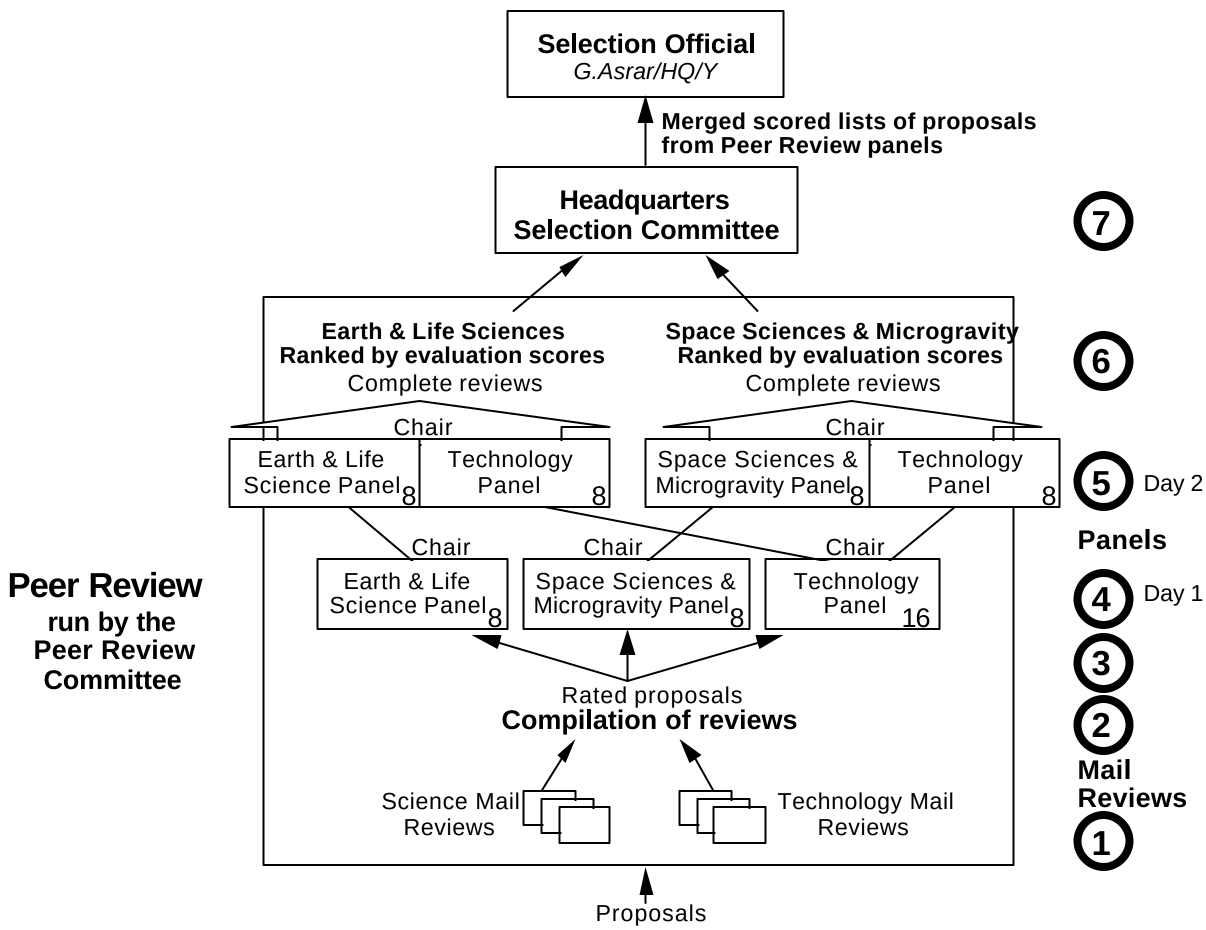

Figure 6-1: Selection Process for ESS Round-3 Investigations

ESS negotiates approximately 14 milestones, payments, and due dates with each Investigator Team based on the template of 12 required milestones [numbered A-L] published in the CAN and shown in Figure 6-2 below. Several categories of optional milestones are also presented in the CAN. The CAN gives examples of each milestone.

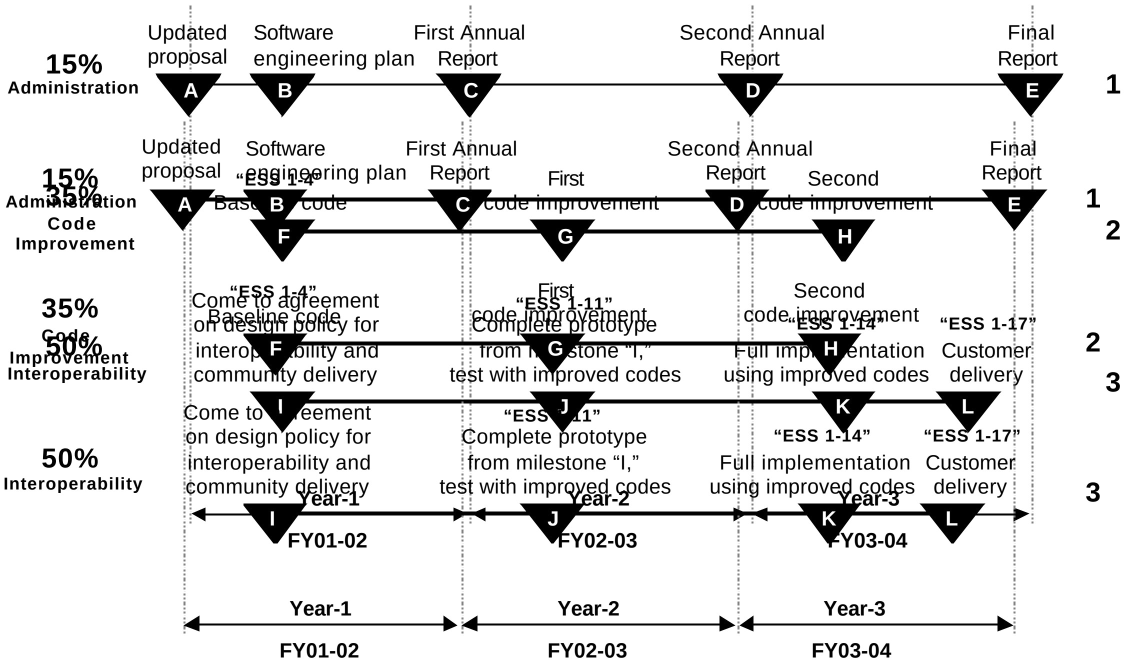

Figure 6-2: Milestone Template for ESS Round-3 Investigations

Following completion of negotiations with each Team, GSFC signs Cooperative Agreements [ESS milestone 1-2] with each Investigator's institution. Over the subsequent 3 years, GSFC and JPL then share the responsibility of validating each milestone achievement submission prior to issuing payment. Twelve ESS Milestones between 1-3 and 1-19 tally the achievement of Investigator milestones A-L as shown in Figure 6-3 below. The success metric for each is stated in Table 7-1.

ESS Milestone	Investigator milestone tallied
1-3	A
1-4	F
1-5	B
1-6	I
1-8	C
1-9	G

ESS Milestone	Investigator milestone tallied
1-11	J
1-12	D
1-13	H
1-14	K
1-17	L
1-19	E

Figure 6-3: Linkage of ESS Milestones to Round-3 Investigator Milestones

After the Round-3 Investigators begin work, ESS will issue a secondary solicitation for plug-in applications modules to enrich the framework environments of the selected Teams [ESS milestones 1-7, and 1-15]. At the end of Round-3 the Science Team will prepare a final report of its findings for the Associate Administrators of the Earth and Space Science Enterprises [ESS milestone 1-20].

ESS *computing testbeds* provide Investigator Teams with access to significant computing resources and applications support to assist them to achieve their code improvement milestones. The development of ESS Testbeds will ensure that high-end scalable computer systems evolve in a direction that leads to sustainable and usable teraflops for ESS applications. The ESS Testbeds activity will be coordinated with those NASA projects that are customers of the ESS-developed software technologies so that production and operational platform capacity will more likely be available for their use once the ESS-sponsored research is completed. ESS will actively facilitate restructuring and movement of codes to very inexpensive, commodity-based, high-performance systems that currently have high interprocessor latency, much less mature system software, little vendor support, and little applications support. ESS plans to provide a capability computing Testbed sized to meet the negotiated requirements of the selected Round-3 Teams [ESS milestones 2-1, 2-2, 2-3, and 2-5]. It may be jointly acquired with other projects that require high-end computing to give ESS access to significantly more capability computing resources than it could purchase alone. Stable hardware and operating systems, the availability of standard programming languages, and sufficient I/O bandwidth and network connectivity are prerequisites to these requirements. ESS milestone 2-1 plans an ESS decision as to the multiyear acquisition approach. ESS will also provide a commodity-based cluster running the Linux operating system sized by Investigator needs [ESS Milestone 2-4, 2-7]. ESS will give scientists from the broader Earth and space sciences community who receive NASA funding but are not supported by ESS access to the Testbeds to assist them in preparing to use scalable parallel systems [ESS milestone 2-6]. ESS Investigators reside at research institutions spread across the U.S. and gain access to the Testbeds through national high-speed network links.

The ESS *system software* research and development activities have been designed with the goal of making high-end scalable computer systems an integral part of large-scale computing resources in the Earth and space sciences and to make them much more cost effective. In these science communities, applications are increasingly complex and in a continuing state of flux, evolving as the scientific understanding of the problems evolve, and using a series of computer systems because their life time exceeds that of any single high-end computer platform. Primary computing system requirements include: tools and techniques that support achievement of interoperation among major application components with relative ease while simultaneously achieving high performance; tools that allow use of advanced high-performance computational methods by a broad range of users; techniques that allow for rapid porting and tuning of evolving applications to the available architectures; and visualization tools accessible from remote locations capable of handling the data volumes associated with teraflops systems. The requirement for mature parallel software environments is not unique to ESS, and the Project collaborates with and leverages complementary work taking place in other HPCC projects within NASA and other Federal agencies. In particular, ESS collaborates with CAS in mutually beneficial areas including frameworks for software interoperability, visualization, and adaptive mesh refinement.

ESS is focusing its system software R&D efforts on four major thrusts that address these requirements while leveraging other research groups and vendors to provide other software tools:

1) Facilitate evolution of an Earth System Modeling Framework. ESS has set an objective in Round-3 of facilitating movement of a critical mass of the NASA Earth system modeling community to a common modeling infrastructure, a step they have called for, by actively facilitating the joint definition of an Earth System Modeling Framework (ESMF) by this community and migration of their codes to this framework. This work applies software engineering practices to address the technical needs of that community throughout Round-3. [ESS milestones 3-4, 3-9, 3-11, 3-12, and 3-14]

2) Provide practical parallel Adaptive Mesh Refinement packages that do not require sophisticated knowledge to use. Adaptive mesh refinement (AMR) is an advanced numerical

technique increasingly popular in the scientific and engineering communities for large-scale applications that cannot achieve the required spatial resolution with uniform meshes. AMR can significantly improve computational and computer memory efficiency by devoting finite CPU and memory resources to computational regions where they are most needed, thus making it possible to compute an accurate numerical solution of a much larger problem than would be possible if using a global fine mesh. GSFC is developing a structured mesh AMR package, while JPL is developing an unstructured mesh package. [ESS milestones 3-1, 3-2, 3-6, 3-7, and 3-10]

3) Develop new methods to visualize massive data sets produced by ESS applications. High-end applications create new problems involving the analysis and visualization of the resulting data sets. 4-D simulation and remote sensing datasets that are produced and consumed on these machines are often too large to be transferred to or stored at an Investigator's local site in their entirety. ESS is enhancing low-end workstation tools to make use of HPC technology. The data access, rendering, display, and user interface modules are developed to execute in a distributed environment. [ESS milestones to be defined after selection of Round-3 Investigations]

4) Leverage the Linux operating system. ESS will bring very inexpensive high-performance parallel computing to the NASA science user environment by leveraging the Linux operating system and the computer industry's investment in mass market technology. ESS has played a leadership role in moving parallel Linux clusters to the production computing floor for some applications, but much system software, taken for granted on commercial systems, is still needed to make them generally useful. In Round-3, ESS will stress test Linux clusters with Investigator codes, develop system software to overcome key shortcomings, and motivate the development of latency-tolerant computational techniques capable of achieving new levels of cost-effective high-performance computing. It is anticipated that system vendors of Linux clusters will rapidly incorporate ESS system software innovations into their products. [ESS milestones 3-3, 3-5, 3-8, and 3-13]

The NASA Research and Education Network (NREN) Project, managed at ARC, cooperates with ESS to support the development and prototyping of NREN/ESS networking research and applications aiming to push the envelope of distributed science computation and visualization over high-performance research and education networks (HPRENs). Especially relevant would be such networking research activities as distributed "middleware" for security or multicast or provision and measurement of end-to-end quality of service (QoS), at very high speeds over multiple HPRENs.

ESS collaborates with the HPCC Learning Technologies (LT) Project to transition ESS Investigator technologies into effective and timely spin-offs. As part of the Round-3 CAN, ESS will identify ways for making materials and knowledge coming out of Round-3 Investigations available to the public or for use in formal and informal education in the U.S. ESS will also identify ways for making problem solving approaches, algorithms, modules, or data products coming out of Round-3 Investigations useful to public organizations such as state and local governments and private industry. [ESS milestone 1-17]

ESS *Basic Research and Human Development* activities support high risk research, undergraduate student stipends, Postdocs, and education outreach. Currently this includes support for next generation computer architectures such as the Hybrid Technology Multi Threaded (HTMT) Architecture, six NASA Graduate Student Research Program Fellows, two NRC Postdocs, and the NASA Summer School for High Performance Computational Earth and Space Sciences.

ESS operates a Guest Investigator facility at GSFC to house members of Investigator Teams when they visit to work closely with the Testbed vendor and NASA inhouse computer and computational scientists. ESS supports the Scientific Visualization Studio at GSFC for the purpose of developing visualization products for Investigator Teams. The mass storage facilities at GSFC are made available to ESS Investigators during the period of their award to store Investigation data sets.

6.3 Evaluation

ESS will perform evaluation throughout Round-3 to identify and understand the critical success factors for the selected Investigations [ESS milestones 1-1, 1-10, 1-16, and 1-18]. The characteristics of the codes that affect performance and interoperability as well as characteristics of the Testbeds that affect performance and usability will be assessed. ESS will collaborate with groups performing basic research into next-generation computing systems to provide them with test codes and application characterizations from the Round-3 applications codes to ensure that their research addresses the computational requirements originating in NASA science. This work is coordinated by the Lead for Evaluation.

7. SCHEDULES

Table 7-1 lists the 41 ESS Project Milestones chronologically by Work Breakdown Structure (WBS) (see definition of the ESS WBS in section 10.2). A due date and a metric is shown for each milestone. ESS Project milestones use a numbering scheme "a-b" ["a" refers to the ESS Work Breakdown Structure, and "b" is a sequence number].

Table 7-2 lists the ESS Project Milestones along with the HPCC PCA and Program Milestones under which they fall. Due dates are shown for each milestone. Major ESS Project milestones share the same metrics with pertinent HPCC Program milestones by design. PCA and Program milestones are numbered consistently with the HPCC Program Plan. Program milestones use a numbering scheme "c.d" ["c" refers to PCA-"c," and "d" is a sequence number].

Figure 7-1 is a Gantt chart showing all ESS Project Milestones along with the HPCC PCA and Program Milestones under which they fall. This figure needs to be viewed in color to see all of its information. This Gantt chart format is not able to show how ESS Project Milestones support Program Milestones – this information is only captured in Table 7-2.

Only current and future ESS Project milestones are shown in Tables 7-1 and 7-2 and Figure 7-1. Archival data, including a complete list of the ESS Level-1 and -2 milestones since the beginning of the Project in FY 1992 along with the status of each, can be found in the July 1998 *ESS Level-2 Project Plan*. The current Program and Project Plans use a milestone numbering system different than that used in the archival data.

Table 7-1: ESS Project Milestones

ESS Project Milestones	**Due Date**	**Output Metrics** *(Those shared by the Program and Project level begin "[Program c.d]")*
1-1 Enhance evaluation software instrumentation package.	9/00	Provide documentation and robustness for use by non-developer.
1-2 Investigator Cooperative Agreements signed.	1/01	80% Teams.
1-3 Investigator proposals updated.	1/01	80% Teams. Tallies Investigator milestone-A.
1-4 Investigator model, assimilation and data analysis codes baselined. Codes delivered on the web.	3/01	80% Teams baseline one or more codes establishing negotiated science metrics. Tallies Investigator milestone-F.

1-5 Investigator software engineering plans in place.	3/01	80% Teams. Tallies Investigator milestone-B.
1-6 Investigators agree to policy for framework design.	5/01	80% Teams proposing to use a frame-work. Tallies Investigator milestone-I.
1-7 Initial plug-in awards made.	7/01	80% of awards made from the first group selected for award.
1-8 Investigator Annual report.	8/01	80% Teams. Tallies Investigator milestone-C.
1-9 Investigator first code improvement.	9/01	[Program 1.3] 30% of ESS Round-3 applications operating at 3X improvement using negotiated science metrics over baseline at the start of Round-3. Tallies Investigator milestone-G and commodity optional milestones.
1-10 Characterize Investigator baseline codes and predict characteristics of first code improvement on testbeds.	6/01	[Program 1.3] 90% of Round-3 codes with capabilities for automated performance monitoring and characterization.
1-11 Investigator codes interoperating within communities using prototype frameworks.	3/02	[Program 3.1] Prototype Earth and space science frameworks impacting at least 5 scientific communities with interoperability among 2 or more applications per framework. 3 applications interoperating within a prototype Earth System Modeling Framework. Integration of new module into framework within 1 day; portability to new computing system within 1 week. Tallies Investigator milestone-J.
1-12 Investigator Annual report.	8/02	80% Teams. Tallies Investigator milestone-D.
1-13 Investigator second code improvement.	8/02	50% of ESS Round-3 applications operating at 10X improvement using negotiated science metrics over baseline at the start of Round-3. Tallies Investigator milestone-H and commodity optional milestones.
1-14 Significant scientific improvement of Investigator codes while conforming to interoperation standards.	9/02	[Program 5.5] 10X improvement using negotiated science metrics over baseline at start of Round-3 in 50% of all applications while interoperating among 2 codes. Tallies Investigator milestone-K.
1-15 Enrich framework environments with needed high-performance plug-in modules.	9/02	[Program 5.5] 20 high-performance modules compatible with existing frameworks.
1-16 Characterize Investigator first code improvement and predict characteristics of second code improvement on testbeds.	6/02	90% of Round-3 codes.
1-17 Sustainable customer use of Investigator code components.	9/03	[Program 6.1] 25 scientific research groups using applications supporting NASA science objectives operating at 10X improvement using negotiated science metrics over baseline at start of Round-3; 10 groups interoperating

		with stable Earth and space science frameworks impacting 5 scientific communities (2 per framework; 3 for Earth System Modeling Framework). Tallies Investigator milestone-L.
1-18 Characterize Investigator second code improvement and predict characteristics of desired science codes on anticipated architectures.	6/03	90% of Round-3 codes.
1-19 Investigator Final report.	1/04	80% Teams. Tallies Investigator milestone-E.
1-20 Final report from Round-3 Science Team.	1/04	Submitted for publication, at least as a NASA technical document.
2-1 Testbed(s) approach decision point.	9/00	Detailed analysis of options and resulting decision, documented in presentation form.
2-2 Install Testbed for baselining ESS Round-3 codes.	9/00	[Program 1.1] Integrated hardware and software to provide a computing and communications testbed for HPCC applications capable of 250 gigaflops (benchmarks) and 3 locations with gigabit WAN capability.
2-3 Teraflops Scalable Testbed, sized to provide resources required by negotiated Team milestones, integrated with gigabit WAN.	7/01	Install Testbed satisfying Teams' requirements for 3x code improvement milestone as determined during negotiation/renegotiation of Team milestones.
2-4 Commodity Based Testbed sized to provide performance required by negotiated Team milestones.	3/02	Upgrade existing Testbed satisfying Teams' requirements as determined during negotiation/renegotiation of Team milestones, operate with 95% availability over 3 months.
2-5 Teraflops Scalable Testbed, sized to provide resources required by negotiated Team milestones, integrated with gigabit WAN.	6/02	Upgrade existing Testbed satisfying Teams' requirements for 10x code improvement milestone as determined during negotiation/renegotiation of Team milestones, operate with 95% availability over 3 months.
2-6 Earth and space science customer community using Investigator code components.	4/03	10 Guest Investigators using Round-3 application code components.
2-7 Achieve dramatic price/performance improvement for Earth and space science applications.	9/04	[Program 7.1] Demonstrate 50 gigaflops sustained applications performance at $250K for 50% of Round-3 Investigations.
3-1 First draft of latency tolerant PARAMESH version 2.0 written directly in MPI.	9/00	Successfully execute the version 2.0 test program suite (as described in NASA/CR-1999-209483) on a Linux cluster (i.e. high latency) machine, without use of the MMPI and SHMEM libraries.
3-2 Fully portable library for PYRAMID supporting multiple 3D mesh data formats	9/00	Demonstrate a single version of the 3D library that compiles and runs on the following 3 parallel machines: Cray T3E, Linux-Cluster, and Origin 2000 for a selected test suite of meshes.

3-3 Release cluster software solicitation.	9/00	Identifies at least 6 problems or problem areas that need solutions.
3-4 Final Earth System Modeling Framework requirements review.	3/01	Joint statement of goals for the ESMF framework. List of science requirements approved by all Round-3 ESMF Teams which include at least 5 disciplines.
3-5 Initial cluster software awards.	3/01	At least 6 negotiated awards.
3-6 Final memory efficient latency tolerant version of PARAMESH written directly in MPI.	9/01	Profile the communication costs within a typical application on both high latency (i.e. Linux cluster) and low latency (i.e. T3E or SGI Origin) machines. Demonstrate that the communication overhead (measured as a percentage of total execution time) on the high latency machine is within 5% of the same measure on the low latency machine(s).
3-7 High-performance fully scalable library for PYRAMID supporting boundary condition data structures.	9/01	Demonstrate query operations for 2 different mesh boundary structures without reduced performance.
3-8 Initial cluster software deliveries.	9/01	At least 3 solutions.
3-9 Earth System Modeling Framework detailed design review, test and validation plan.	12/01	Successful formal design review of the ESMF with documentation that supports requirements linked to each Investigator as established in milestone 3-4; test and validation plans delivered to the Government; quantified validation metrics.
3-10 Deliver high-performance AMR packages useful to the ESS community	3/02	[Program 3.1] Two portable parallel latency-tolerant adaptive mesh refinement packages.
3-11 Delivery of functioning Earth System Modeling Framework prototype.	3/02	Demonstration of prototype ESMF including at least 3 disciplines represented by the Round-3 ESMF Teams, with framework overhead no more than 100%.
3-12 Remaining functionality implemented in Earth System Modeling Framework, testing and validation complete.	12/02	Demonstration of ESMF that passes the test and validation plan defined in milestone 3-9, including at least 3 disciplines represented by Round-3 ESMF Teams with framework overhead no more than 20%.
3-13 Improve the commodity cluster software environment strategically for the benefit of the ESS community.	12/02	[Program 2.2] Production-ready commodity-based cluster computing runtime and development environments portable to three Linux-based testbeds from different vendors.
3-14 Provide a viable Earth System Modeling Framework.	9/03	[Program 3.3] Portable production-ready Earth System Modeling Framework incorporating 5 disciplines.

Table 7-2: ESS Project Milestones with HPCC PCA/Program Milestones

PCA and Program Milestones	**Due Date**	***ESS Project Milestones***	**Due Date**	**Output Metrics** *(shared by the Program and Project level)*
PCA-1 Develop component technologies for performance	9/01			
1.1 Establish high-performance Testbed for application performance (CAS/ESS/NREN)	9/00	**2-2** Install Testbed for baselining ESS Round-3 codes.	9/00	CAS/ESS/NREN: Integrated hardware and software to provide a computing and communications Testbed for HPCC applications capable of 250 gigaflops (benchmarks) and 3 locations with gigabit WAN capability.

ESS Project milestones necessary for 2-2	*Due*
none	

1.3 Develop and apply technologies to measure and enhance performance on high performance testbeds (CAS/ESS/NREN)	9/01	**1-9** Investigator first code improvement.	9/01	ESS: 30% of ESS Round-3 applications operating at 3X improvement using negotiated science metrics over baseline at the start of Round-3.
		1-10 Characterize Investigator baseline codes and predict characteristics of first code improvement on testbeds.	6/01	ESS: 90% of Round-3 codes with capabilities for automated performance monitoring and characterization.

	ESS Project milestones necessary for 1-9	*Due*
2-1	*Testbed(s) approach decision point.*	*9/00*
1-2	*Investigator cooperative agreements signed*	*1/01*
1-3	*Investigator proposals updated*	*1/01*
1-4	*Investigator model, assimilation, and data analysis codes baselined. Codes delivered on the Web.*	*3/01*
2-3	*Teraflops Scalable Testbed, sized to provide resources required by negotiated Team milestones, integrated with gigabit WAN.*	*7/01*

	ESS Project milestones necessary for 1-10	*Due*
1-1	*Enhance evaluation software instrumentation package*	*9/00*

PCA and Program Milestones	**Due Date**	***ESS Project Milestones***	**Due Date**	**Output Metrics** (shared by the Program and Project level)

PCA-2 Develop component technologies for reliability and resources management	6/03			
2.2 Develop embedded tools and services for autonomous resource estimation/request of local and distributed ground based systems (CAS/ESS/NREN)	12/02	**3-13** Improve the commodity cluster software environ-ment strategically for the benefit of the ESS community.	12/02	ESS: Production-ready commodity-based cluster computing runtime and development environments portable to three Linux-based testbeds from different vendors.

ESS Project milestones necessary for 3-13		*Due*
3-3	*Release cluster software solicitation*	*9/00*
3-5	*Initial cluster software awards*	*3/01*
3-8	*Initial cluster software deliveries*	*9/01*

PCA and Program Milestones	**Due Date**	***ESS Project Milestones***	**Due Date**	**Output Metrics** (shared by the Program and Project level)
PCA-3 Develop component technologies for interoperability and portability	9/03			
3.1 Tools and techniques for interoperable and portable applications in aerospace, Earth science, and space science communities (CAS/ESS)	3/02	**1-11** Investigator codes interoperating within communities using prototype frameworks.	3/02	ESS: Prototype Earth and space science frameworks impacting at least 5 scientific communities with interoperability among 2 or more applications per framework. 3 applications interoperating within a prototype Earth System Modeling Framework. Integration of new module into framework within 1 day; portability to new computing system within 1 week.
		3-10 Deliver high-performance AMR packages useful to the ESS community	3/02	Two portable parallel latency-tolerant adaptive mesh refinement packages.

ESS Project milestones necessary for 1-11		*Due*
1-5	*Investigator software engineering plan*	*3/01*
1-6	*Investigators come to agreement on policy for framework design*	*5/01*

ESS Project milestones necessary for 3-10		*Due*
3-1	*First draft of latency tolerant PARAMESH version 2.0 written directly in MPI.*	*9/00*
3-2	*Fully portable library for PYRAMID supporting multiple 3D mesh data formats*	*9/00*
3-6	*Final memory efficient latency tolerant version of PARAMESH written directly in MPI*	*9/01*
3-7	*High-performance fully scalable library for PYRAMID supporting boundary condition data structures.*	*9/01*

3.3 Interoperable and portable systems, services and environments (CAS/ESS)	9/03	**3-14** Provide a viable Earth System Modeling Framework.	9/03	ESS: Portable production-ready Earth System Modeling Framework incorporating 5 disciplines.

ESS Project milestones necessary for 3-14		*Due*
3-4	*Final Earth System Modeling Framework requirements review*	*3/01*
3-9	*Earth System Modeling Framework detailed design review, test and validation plan*	*12/01*
3-11	*Delivery of functioning Earth System Modeling Framework prototype*	*3/02*
3-12	*Remaining functionality implemented in Earth System Modeling Framework, testing and validation complete*	*12/02*

PCA and Program Milestones	**Due Date**	***ESS Project Milestones***	**Due Date**	**Output Metrics** (shared by the Program and Project level)
PCA-5 Demonstrate integrated HPCC technologies	9/02			
5.5 Demonstrate significant improvements in Earth and space science application codes (ESS)	9/02	**1-14** Significant scientific improvement of Investigator codes while conforming to interoperation standards **1-15** Enrich framework environments with needed high-performance plug-in modules.	9/02 9/02	ESS: 10X improvement using negotiated science metrics over baseline at start of Round-3 in 50% of all applications while interoperating among 2 codes. 20 high-performance modules compatible with existing frameworks.

ESS Project milestones necessary for 1-14		*Due*
2-5	*Teraflops Scalable Testbed, sized to provide resources required by negotiated Team milestones, integrated with gigabit WAN.*	*6/02*

1-16	*Characterize Investigator first code improvement and predict characteristics of second code improvement on testbeds.*	*6/02*
1-13	*Investigator second code improvement*	*8/02*

ESS Project milestones necessary for 1-15		*Due*
1-7	*Plug-in awards made*	*7/01*

PCA and Program Milestones	**Due Date**	***ESS Project Milestones***	**Due Date**	**Output Metrics** (shared by the Program and Project level)
PCA-6 Demonstrate significant engineering, scientific, and educational impacts from integrated HPCC technologies	9/05			
6.1 Establish impact on Earth and space sciences through the demonstration of production ready high-performance Earth and space science computational simulations validated by NASA Enterprise observational mission data (ESS/NREN)	9/03	**1-17** Sustainable customer use of Investigator code components	9/03	ESS: 25 scientific research groups using applications supporting NASA science objectives operating at 10X improvement using negotiated science metrics over baseline at start of Round-3; 10 groups interoperating with stable Earth and space science frameworks impacting 5 scientific communities (2 per framework; 3 for Earth System Modeling Framework).

ESS Project milestones necessary for 1-17		*Due*
1-8	*Investigator Annual report*	*8/01*
1-12	*Investigator Annual report*	*8/02*
2-6	*Earth and Space Science customer community using Investigator code components.*	*4/03*
1-18	*Characterize Investigator second code improvement and predict characteristics of desired science codes on anticipated architectures.*	*6/03*
1-19	*Investigator Final report*	*1/04*
1-20	*Final report from Round-3 Science Team*	*1/04*

PCA and Program Milestones	**Due Date**	***ESS Project Milestones***	**Due Date**	**Output Metrics** (shared by the Program and Project level)
PCA-7 Establish sustainable and wide-	9/05			

spread customer use of HPCC Program technologies				
7.1 Establish sustained price performance improvements for Earth and space science applications (ESS)	9/04	**2-7** Achieve dramatic price/performance improvement for Earth and space science applications.	9/04	ESS: Demonstrate 50 gigaflops sustained applications performance at $250K for 50% of Round-3 Investigations.

ESS Project milestones necessary for 2-7	*Due*
2-4 Commodity-based Testbed sized to provide performance required by negotiated Team milestones.	*3/02*

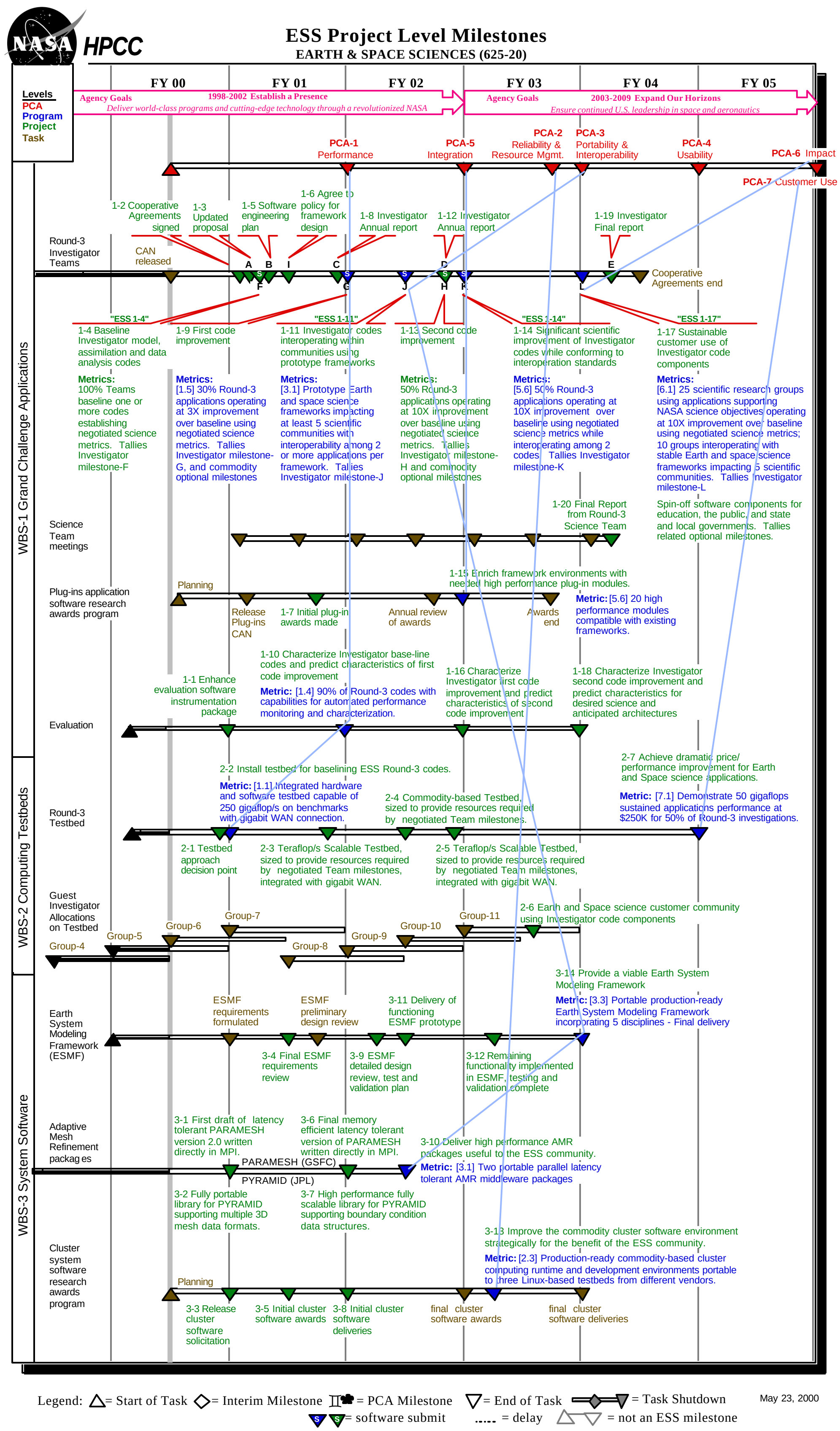

Figure 7-1: All ESS Project milestones in FY 2000-04

8. RESOURCES

Funding and workforce budgets have been coordinated among the various NASA centers participating in the ESS Project. The following two sections present details in these areas.

8.1 Funding Requirements

The Code Y Office of Earth Science program code 625-20 has been assigned to ESS funds. Table 8-1 provides total funding requirements (in $ thousands) for the ESS Project, consistent with the HPCC Program Plan dated May 2000, broken out by participating NASA Center. Table 8-2 further breaks down these funding requirements by WBS. It is anticipated that more than 50% of total ESS funding will be sent outside the Project through award processes to academic, industrial, and other Federal partners, summarized in Table 8-3.

Table 8-1: NASA HPCC/ESS Funding Requirements in $ Thousands

Center	FY99	FY00	FY01	FY02	FY03	FY04	Total
GSFC	9,216	9,797	18,200	18,200	18,200	7,900	81,513
JPL	2,384	2,820	2,700	2,700	2,700	2,400	15,704
ARC	0	7,050	0	0	0	0	7,050
Total ESS	11,600	19,667	20,900	20,900	20,900	10,300	104,267

Table 8-2: ESS Funding Allocation by Major WBS areas in $ Thousands

Funding Allocations	FY00	FY01	FY02	FY03	FY04	Total
GSFC	9,797	18,200	18,200	18,200	7,900	72,297
WBS-1 Applications	*1,490*	*6,864*	*6,761*	*6,761*	*1,735*	*23,611*
WBS-2 Testbeds	*6,012*	*6,875*	*6,875*	*6,875*	*3,000*	*29,637*
WBS-3 System Software	*938*	*1,373*	*1,373*	*1,373*	*736*	*5,793*
WBS-5 Basic Research and Human Development	*220*	*1,770*	*1,873*	*1,873*	*1,243*	*6,979*
WBS-6 Management	*1,137*	*1,318*	*1,318*	*1,318*	*1,186*	*6,277*
JPL	2,820	2,700	2,700	2,700	2,400	13,320
WBS-1 Applications	*995*	*995*	*995*	*995*	*995*	*4,975*
WBS-2 Testbeds	*808*	*808*	*808*	*808*	*646*	*3,878*
WBS-3 System Software	*644*	*772*	*777*	*777*	*644*	*3,614*
WBS-5 Basic Research and Human Development	*246*	*0*	*0*	*0*	*0*	*246*
WBS-6 Management	*127*	*125*	*120*	*120*	*115*	*607*
ARC	7,050	0	0	0	0	7,050
WBS-2 Testbeds	*7,050*	*0*	*0*	*0*	*0*	*7,050*
Total ESS	19,667	20,900	20,900	20,900	10,300	92,667

Table 8-3: Funding Allocation for Major ESS Acquisitions in $ Thousands

Funding Allocations	FY00	FY01	FY02	FY03	FY04	Total
Round-3 Investigator Cooperative Agreements	1,500	5,000	5,000	5,000	1,500	18,000
Teraflops Scalable Testbed	9,150	5,000	4,000	4,000	500	22,650
Plug-ins Development Awards	0	1,000	2,000	2,000	1,000	6,000
Cluster Software Research Awards	0	850	1,300	1,300	500	3,900
Total for Major ESS Acquisitions	10,650	11,850	12,300	12,300	3,500	50,550

8.2 Institutional Requirements

The Civil Servant, inhouse support service contractor (SSC), and performance-based contract (PBC) workforce allocated to the ESS Project are shown in Table 8-4. All entries are in full-time equivalent (FTE) work-years.

Table 8-4: NASA HPCC/ESS Workforce Summary (FTE)

Category	FY99	FY00	FY01	FY02	FY03	FY04
GSFC Civil Service	11.5	15.0	15.0	15.0	16.0	15.0
GSFC SSC and PBC Contractors (non-CS)	23.4	21.4	20.5	20.5	20.5	20.5
JPL Contracted R&D (non-CS)	10.5	11.5	10.5	10.5	10.5	9.5
Total	45.4	47.9	46.0	46.0	47.0	45.0

Table 8-5: ESS/GSFC Civil Service Workforce Summary by WBS (FTE)

Workforce Allocations	FY00	FY01	FY02	FY03	FY04
GSFC	15.0	15.0	15.0	16.0	15.0
WBS-1 Applications	*1.5*	*1.6*	*1.6*	*1.9*	*1.6*
WBS-2 Testbeds	*6.8*	*7.4*	*7.4*	*7.7*	*7.4*
WBS-3 System Software	*2.0*	*2.1*	*2.1*	*2.3*	*2.1*
WBS-5 Basic Research and Human Development	*0*	*0*	*0*	*0*	*0*
WBS-6 Management	*4.7*	*3.9*	*3.9*	*4.1*	*3.9*

9. CONTROLS

The process for controlling changes of the ESS Project and its subordinate tasks is hierarchical and described in this section.

9.1 Project Changes

The HPCC Program Commitment Agreement (PCA), the HPCC Program Plan, and each Project Plan (CAS, ESS, REE, NREN, and LT) are controlled documents. The retention, updating, and approval of these documents is controlled as follows:

Document	**Retains Approved Documents**	**Preparation of Updated Documents**		**Approves Documents**
		Primary	**Supporting**	
Program Commitment Agreement	NASA HQ Program Office	HPCC EC	Program Office	Administrator
Program Plan	Program Office	Program Office	Project Offices	HPCC EC AA – (Codes F,R,S and Y)
Project Plans	Project Offices	Project Offices	Task Managers Performing Orgs.	Program Manager

Figure 9-1: HPCC Document Control Summary

Any change to the HPCC Program or an HPCC Project that alters the commitments within a controlled document must be approved by the approving official(s) for all levels of documents impacted by the proposed change. The PCA, Program Plan, and Project Plans include change logs that document all changes from the beginning of the HPCC Program to the date of the latest approved change. The ESS Project Manager maintains the Project change log.

9.2 Computing and Networking Testbeds

All participants in the NASA HPCC Program must comply with current NASA security policies regarding access to networks and computers.

9.3 Sensitive Technology

NASA Center management, working with industry and NASA HPCC researchers, are responsible for identifying sensitive technologies. These technologies are handled in such a way that their dissemination to foreign persons, companies, laboratories, and universities is restricted.

Sensitive information that is generated under formal cooperative research agreements between NASA and non-Federal parties is protected by the amended (October 1992) NASA Space Act of 1958. Data produced under such an arrangement will be protected from Freedom of Information Act requests for a period of 5 years after the date of dissemination.

Negotiated License Agreements are used to restrict access to privately developed technology performed under the auspices of the NASA HPCC Program. These agreements provide NASA with limited rights to use proprietary data or designs in NASA inhouse or cooperative research projects. These agreements specify limits on the distribution and use of the proprietary data by NASA and NASA-licensed entities.

Some software and information developed within the NASA HPCC Program may be subject to protection under the Export Administration Regulations or the International Traffic in Arms Regulations, which are export controls established by law. HPCC Program participants will follow applicable export control laws. These regulations establish lists or categories of technical data and/or products that may not be exported without an approved export license. (Note that the definition of "exported" includes "disclosed" and "discussed" as well as published.)

10. IMPLEMENTATION APPROACH

10.1 Implementation Approach

During FY 2000-04 it is anticipated that a majority of the total ESS funding will be paid out to Investigator Teams through Cooperative Agreements for outsourced advanced software technology development and to industrial partners through contracts for Testbed access and support:

- The development of most ESS software technology is done out-of-house. Due to the technical challenge of several key software-related ESS Project milestones, ESS has focused most of its planning activities as well as its funding and human resources on their achievement. The required development work will be performed under Cooperative Agreements. Full and open competitive procurements are used to the maximum extent possible. Section 1.3 above describes ESS's past solicitations. ESS plans to issue a Cooperative Agreement Notice (CAN) in FY 2000 to select Round-3 Investigator Teams for funding in FY 2000-04. This process is described in Section 6.2.
- ESS intends to acquire a capability computing testbed, the Teraflops Scalable Testbed, to enable the Round-3 Investigators to achieve their negotiated milestones. ESS will acquire this testbed jointly with other projects that require high-end computing, giving Round-3 Investigators access to significantly more capability computing resources than ESS could purchase alone. ESS prefers to pay for access to computing capability over some period of time and not purchase hardware. The capability will be sized to meet the requirements stemming from the code improvement milestones negotiated with the Round-3 Teams up to the financial constraints of the Project. These requirements scale up over time. ESS intends to include in the Testbed agreement a provision incentivizing application performance support to assist the Round-3 Investigators in achieving the performance metrics of their code improvement milestones. Full and open competitive procurements are used to the maximum extent possible.

Small staffs of technologists are maintained at GSFC and JPL to assist ESS in preparing the CAN, running the solicitation, negotiating the milestones, and validating milestone achievement. Staff members facilitate transfer of the technologies developed by the Investigator Teams to the broader NASA science communities and develop technologies of general use to those communities. These "Inhouse" staff members are brought in through institute arrangements with universities, and performance-based contractors in some cases.

The SEWP II contract is used for major equipment purchases in instances where a new full and open competition is not appropriate. Interagency agreements for joint R&D endeavors and the utilization of early prototype systems are also used.

10.2 ESS Summary Work Breakdown Structure

All work funded by ESS falls within one of five WBS areas:

- WBS-1 Grand Challenge Applications and Algorithms
- WBS-2 Computing Testbeds
- WBS-3 System Software Research and Development
- WBS-5 Basic Research and Human Development
- WBS-6 Management

11. ACQUISITION SUMMARY

As described above in Section 10, the ESS Round-3 CAN, summarized in Table 11-1, is the major acquisition planned by ESS in the FY 2000-04 time frame and from proposals submitted to it, Headquarters will select Round-3 Investigator Teams. The Teraflops Scalable Testbed(s) will be provided to support the Round-3 Investigators; options for acquisition(s) may include but are not limited to those summarized in Table 11-2; a major decision point for selecting the approach for acquisition of the testbed(s) is scheduled for September 2000. It is planned that once the Round-3 Cooperative Agreements have been signed, ESS will carry out two secondary solicitations on research topics supporting the work of the Round-3 Teams: one for plug-in application codes, summarized in Table 11-3, and the other for cluster system software, summarized in Table 11-4.

Table 11-1: Round-3 CAN Acquisition Summary

Category	*Description*
Element	Round-3 Science Investigations
Type of procurement	Cooperative Agreement Notice (CAN); full and open
Type of contract	Cooperative agreements with approximately 10Investigator institutions
Source	Teams based at universities and Federal labs
Procurement activity	- GSFC issues the CAN and receives proposals - Headquarters oversees the peer review - Headquarters makes the selections for negotiations - ESS staff at GSFC/JPL negotiate technical milestones with Teams - GSFC signs Cooperative Agreements with the selected institutions - GSFC provides Technical Officers for the cooperative agreements
Technical monitoring	ESS staff at GSFC/JPL validate milestone achievement prior to payment. Each cooperative agreement contains approximately 14 milestones.

Table 11-2: Teraflops Scalable Testbed Acquisition Summary

Category	*Description*
Element	Teraflops Scalable Testbed(s)
Type of procurement	Jointly with several other NASA high-performance computing activities. Options: 1) Issue task on an existing GSA contract, and/or 2) Issue RFP, and/or 3) Purchase off SEWP II contract.

Type of contract	Jointly with several other NASA high-performance computing activities: 1) Task on an existing GSA contract, and/or 2) Multiyear GSFC contract, and/or 3) Exercise SEWP II contract line items.
Source	1) Integrator of high-end computing systems, and/or 2) Vendor of high-end computing systems, and/or 3) Vendor of high-end computing systems.
Procurement activity	1) GSFC issues task to GSA contract and monitors Integrator performance, and/or 2) GSFC issues RFP, runs SEB process, negotiates terms of contract, provides Technical Officer for contract, and signs contract, and/or 3) ARC exercises SEWP II contract line items
Technical monitoring	1) ESS monitors task performance and modifies task as needed, and/or 2) ESS monitors contract performance, modifies contract as needed, and/or 3) ESS monitors ARC performance; ARC purchases support and maintenance as needed.

Table 11-3: Plug-ins CAN Acquisition Summary

Category	*Description*
Element	Plug-in application code development
Type of procurement	Cooperative Agreement Notice (CAN); full and open
Type of contract	Cooperative agreements with approximately 10 PI institutions
Source	Teams based at universities and Federal labs
Procurement activity	GSFC issues the CAN, receives proposals, oversees the peer review, makes selections, issues cooperative agreements or grants to the selected institutions, and provides Technical Officers for the awards
Technical monitoring	GSFC evaluates progress reports or milestone deliverables and renews grant awards or validates milestone payments.

Table 11-4: Cluster System Software CAN Acquisition Summary

Category	*Description*
Element	Cluster system software research awards
Type of procurement	Cooperative Agreement Notice (CAN); full and open
Type of contract	Cooperative agreements with approximately 10 PI institutions
Source	Teams based at universities, Federal labs, and in the private sector
Procurement activity	GSFC issues the CAN, receives proposals, oversees the peer review, makes selections for negotiations; GSFC and JPL negotiate performance milestones; GSFC signs cooperative agreements with selected institutions, and provides Technical Officers for the cooperative agreements

Technical monitoring	ESS staff at GSFC/JPL validate milestone achievement prior to payment

12. PROJECT DEPENDENCIES

12.1 Related Activities and Studies

ESS works closely with the NASA Center for Computational Sciences (NCCS) at GSFC in many mutually beneficial ways. ESS supports R&D of direct benefit to the NCCS. The NCCS operates the GSFC-resident ESS Testbeds for ESS. ESS develops high-end applications that may later run in a production environment on NCCS machines. The NCCS provides mass storage for ESS Investigators. ESS provides a training ground for NCCS applications support staff. The NCCS provides ESS with much of its matrixed workforce.

NCCS operates under the umbrella of the Consolidated Supercomputing Management Office (CoSMO) headquartered at ARC. ESS works with CoSMO to assure that ESS research findings transition into production and operational computing use by CoSMO, primarily on the NCCS production floor.

ESS collaborates with the CAS Project in technology areas where the investment of one Project can be leveraged by the other, such as methods for software interoperability, visualization, and adaptive mesh refinement. In addition, ESS and CAS each provide the other Project's Investigators with significant access to its Testbeds.

ESS is developing an agreement with GSFC and ARC to be put in place defining the Code Y (ESS, Data Assimilation Office, and others) relationship to a MOU signed May 1999 between NASA and SGI to investigate collaborations in terascale computing.

ESS collaborates with the HPCC NASA Research and Education Network (NREN) Project managed by ARC on high-speed networking R&D by providing science applications to NREN that NREN will further enable through long distance high performance networking performance-based technologies.

Nine ESS Round-2 Investigator Cooperative Agreements are still active, although they will end in June 2000. They are listed below in Section 13.

12.2 Related Non-NASA Activities and Studies

Since 1992, ESS on behalf of eight HPCC funding Agencies (NIST, DARPA, NSA, EPA, NSF, NASA, DOE, and DOD), has led the multi-agency effort that developed the National HPCC Software Exchange (NHSE). The NHSE now provides an interconnected set of discipline-oriented software and document repositories that encourages software reuse through the sharing of advanced software technology and algorithms among the Federal HPCC participants. The NHSE [http://www.nhse.org] is now in its operational/maintenance phase, being maintained by the University of Tennessee. The ESS software repository is found at http://esdcd.gsfc.nasa.gov/rib/repositories/ESS/catalog/index.html. The types of software being made available include systems software and software tools, basic building blocks for common computational and communication tasks, and research codes for solving difficult computational problems. The NHSE provides a uniform interface built on top of a distributed set of discipline-oriented repositories. The interface assists the user in locating and retrieving relevant resources. The NHSE provides member sites with the Repository-In-a-Box (RIB) software, a suite of tools for setting up and maintaining a repository and for linking it in with the NHSE. The CICR&D Working Group on High End Computing and Computation (HECCWG) provides interagency oversight of the NHSE.

13. AGREEMENTS

13.1 NASA Agreements

MOU being finalized between ESS and the Software Assurance Technology Center at GSFC for assistance in reviewing proposals to the ESS Round-3 CAN and monitoring the subsequent cooperative agreements.

13.2 Non-NASA Agreements

The following 8 non-NASA ESS Round-2 Investigator Cooperative Agreements were put in place by ESS in 1996 and will end in June 2000.

Table 13-1: Non-NASA ESS Round-2 Investigator Cooperative Agreements

Agreement number	Principal Investigator	Institution	Title
NCCS5-147	Peter Olson	Johns Hopkins University	3-D Spherical Simulations of the Earth's Core and Mantle Dynamics
NCCS5-149	Roberto Mechoso	University of California at Los Angeles	Development of an Earth System Model: Atmosphere/Ocean Dynamics and Tracers Chemistry
NCCS5-150	Peter Lyster	University of Maryland at College Park	Four Dimensional Data Assimilation: Investigation of High Performance Computing and Current Algorithms at Goddard Data Assimilation Office
NCCS5-154	Graham Carey	University of Texas at Austin	Scalable Parallel Finite Element Computations of Rayleigh-Benard-Marangoni Problems in a Microgravity Environment
NCCS5-151	Andrea Malagoli	University of Chicago	Turbulent Convection and Dynamos in Stars
S-77096-F	John Gardner	Naval Research Laboratory	Understanding Solar Activity and Heliospheric Dynamics: A Grand Challenge for HPCC
NCCS5-146	Tamas Gombosi	University of Michigan	Parallel Adaptive Methods for Multiscale Modeling of the Heliosphere
NCCS5-153	Paul Saylor	University of Illinois at Urbana-Champaign	A Multipurpose 3-D Code for Relativistic Astrophysics & Gravitational Wave Astronomy: Application to Coalescing Neutron Star Binaries

14. PERFORMANCE ASSURANCE

14.1 General

ESS Project deliverables are assessed against a variety of metrics that are defined in Section 2. A milestone is considered complete when the success criteria for all the metrics that apply to it have been met or exceeded.

14.2 Solicitation Processes

The ESS Round-3 CAN is the primary requirements document for the ESS Round-3 activities. This document describes the broad area of work that ESS is interested in supporting but is not specific; this allows proposers the most freedom and flexibility in their responses. The CAN contains an evaluation criteria that is used to point score each proposal during the peer review. The point scoring is the predominant basis used by the Selection Committee for selecting Teams for negotiations.

Following the signing of Round-3 Cooperative Agreements, ESS plans a "Plug-ins" CAN to select and fund algorithmic specialists to develop high-performance plug-in software modules compatible with frameworks for interoperability that Round-3 Teams will have adopted or developed. The Plug-ins CAN is the requirements document for this solicitation; it describes the broad area of work that ESS is interested in supporting. It contains an evaluation criteria that is used to point score each proposal during the peer review. The point scoring is the predominant basis for selection of teams for award.

Following the signing of Round-3 Cooperative Agreements, ESS plans a "Cluster System Software" CAN to select and fund developers of public licensed system software for use in clusters of PCs running Linux. The Cluster System Software CAN is the requirements document for this solicitation; it describes the broad area of work that ESS is interested in supporting. It contains an evaluation criteria that is used to point score each proposal during the peer review. The point scoring is the predominant basis for selection of teams for award.

14.3 Software Performance Verification

ESS Round-3 Investigator Teams work toward achievement of a set of typically 14 negotiated milestones documented in their Cooperative Agreements. Individual milestones address update of proposal, developing a software engineering plan, and establishing a policy for a framework design. Several milestones typically address software code improvement, where the success metric is in units of quality valued by the NASA science community or flight projects. Several milestones typically address code interoperation, where the unit of quality is whether the software functions. Some of the code improvement and interoperation milestones require software release. One milestone is for customer use of codes. Several milestones are for submission of reports. Each milestone is verifiable. When a Team achieves a milestone, they document their achievement and submit it to ESS for verification that involves testing of software or inspection of documents. Once verification is complete, ESS gives the go-ahead to the Team to invoice for payment.

14.4 Software Assurance

ESS Round-3 Teams are encouraged, through several milestones in their Cooperative Agreements, to develop their software engineering infrastructure. A key milestone requires a software engineering plan, which ESS will need to validate. To assure that this infrastructure is adequate, audits may be required.

Commercial off-the-shelf software is used to the greatest extent possible, however, ESS often works with software that is less reliable than desired for the purpose of improving its reliability.

In such cases, ESS works closely with software vendors to correct deficiencies in software provided in this fashion.

14.5 Hardware Performance Verification

Metrics are kept regarding the reliability of the Testbed hardware used in the ESS Project. Commercial off-the-shelf hardware and software is used to the greatest extent possible, however, ESS often works with hardware and software that is less reliable than desired for the purpose of improving its reliability.

15. RISK MANAGEMENT

15.1 Introduction

Risk is inherent in the research and development of new technologies, particularly in the highly dynamic area of high-performance computing and communications. Risks within ESS arise from two general sources: technical risk resulting from unexpected technical difficulties and programmatic risks that involve factors beyond the control of the ESS Project and sometimes beyond the control of NASA. ESS has in place a process that identifies its risks and that provides early warning of high-level risks.

15.2 Overview of Process

Risks are identified within the Project on a continuous basis. A current list of Project-level risks is presented in Section 15.4. A three-level risk exposure analysis has been applied to this list by rating the probability and impact of the risks as low, medium, or high. This results in nine distinct values of risk exposure, allowing a ranking of risks. The ESS Project Manager reviews risks on an annual basis concurrent with the review of the Project's controlled documents (see Section 9.1). Program reviews, identified in Section 20, are essential elements of the risk identification sub-process.

15.3 Organization

Risk management is performed by the ESS Project Manager, the ESS Associate Project Manager, and ESS Deputy Project Managers.

Progress towards milestones is used as the primary risk indicator for the Project. Due to the milestone hierarchical structure (e.g., multiple task milestones enabling project milestones, multiple project milestones enabling program milestones), this approach provides effective early warning of high-level risk. Progress towards Program and Project level milestones is monitored on a monthly basis via the ESS monthly report and on a quarterly basis through ESS submissions for the Program Office's quarterly status report to the Office of Aerospace Technology. Both the monthly and quarterly reports document progress towards future Project and Program milestones as well as the recent completion of Project and Program milestones.

ESS holds no reserves but constructs a formal descope plan when a descope situation arises. The descope plan involves several steps. First, the range of possible funding cuts is identified, and independently the relative priorities of project activities are assigned; highest priority is to honor existing contractual obligations. Second, plausible descope scenarios, based on priorities, are created having dollar savings which cover the range of possible cuts; at least three scenarios are made, more if the range of possible cuts is large. Third, the impact of each scenario on Project, Program and PCA milestones is estimated. Fourth, the Project uses this information to negotiate its share of the funding cut with the Program Office. When ESS is designing a CAN solicitation, descoping or replanning to a modified funding profile is relatively simple. However, once Cooperative Agreements have been negotiated, descoping or replanning a funding profile is extremely difficult and disruptive to achieving Project objectives.

15.4 Process details

15.4.1 Technical Risk

The four primary ESS technical risks are summarized in Table 15-1. In addition to the risks of technology availability are added the risks involved in managing complex technology development activities.

Table 15-1: ESS Technical Risk Assessment

Risk	Risk Impact	Risk Probability	Risk Probability Mitigation Processes
• Communities of Investigators cannot come to agreement on the policy for the framework.	High	High	• Each Investigator Team is required to have an early milestone to achieve agreement on policy for the framework. • A software engineering integrator proactively facilitates establishing the basis for agreement among the ESMF participants.
• The resulting modeling software lacks fidelity to faithfully model real physical systems.	High	Medium	• The CAN proposal evaluation process eliminates proposals that show poor understanding of model validation including model test procedures.
• Investigator Teams do not hire the disciplined software engineering expertise required to develop the interoperable and high performance codes required. • Investigator Team PIs do not have sufficient motivation or ability to manage their team of multidisciplinary scientists and software technologists to produce a challenging software product on a demanding timeline.	High High	High Medium	• The business model of ESS ties each Team payment to achievement of a negotiated milestone. This motivates and assists the PI and the PI institution to manage the Team well. • ESS selects twice as many teams as are necessary to meet the Project and Program objectives. • The CAN proposal evaluation process eliminates proposals with excessive technical risk. • The Testbed vendor staff and ESS Center-based inhouse team computational scientists tasked to provide innovative solutions in support of PI Teams.
• Science application codes are selected that cannot be adequately parallelized to achieve performance goals.	Medium	Low	• The CAN proposal evaluation process eliminates proposals with excessive management risk. • Testbed vendor is motivated by contract arrangements to assist weak Teams.

15.4.2 Programmatic Risk

To be effective over the long term ESS must not only develop appropriate technologies on schedule but must also assure that its technology targets evolve as needed to meet the changing needs of a vital Enterprise customer and that the developed technologies continue to be useful to the Enterprise science community as a legacy after ESS responsibilities have ended.

The four primary ESS programmatic risks are summarized in Table 15-2. All of these risks are mitigated primarily by strategic and continuing communications between ESS and various management groups within the customer Enterprises.

Table 15-2: ESS Programmatic Risk Assessment

Risk	Risk Impact	Risk Probability	Risk Probability Mitigation Processes
• The NASA production computing infrastructure is not prepared to support the increased resource requirements of ESS Investigator Teams after they have been empowered by ESS technology.	High	Medium	• ESS partners strategically with NCCS and CoSMO in its initiatives to maximize the opportunity for production computing in NASA to anticipate future requirements. • ESS periodically advocates its technology advances directly to Enterprise Science management so that they are aware of emerging capabilities. • ESS invests in approaches that can significantly improve the price/performance ratio of high end computing systems.
• Resulting ESS software technologies do not propagate into and benefit their intended communities.	High	Medium	• ESS designed the Round-3 CAN to emphasize customer use of codes developed including milestones where Investigators identify customer relationships up front and show customer use in the end.
• ESS experiences reduction or loss of funding.	High	Medium	• ESS involves Headquarters customers/stakeholder Enterprises as ongoing front line participants in Round-3 activities so they know the benefits first hand.
• Selected Investigator Teams do not address ESS customer Enterprise requirements.	High	Low	• The Earth Science and Space Science Enterprises jointly participate in selecting the Round-3 Investigators. The Enterprises provide the chair of the Peer Review Committee, provide the chair and members of the Selection Committee, and provide the Selection Official for the CAN.

16. ENVIRONMENTAL IMPACT

The Environmental Impact procedures and guidelines are not applicable to the ESS Project.

17. SAFETY

The performing organizations supporting ESS will strictly support all applicable safety procedures and guidelines.

18. TECHNOLOGY ASSESSMENTS

ESS is a computer research project that pursues technologies that are between 3 and 10 years of maturity. ESS conducts Technology Readiness Level (TRL) 2 - 6 research activities (TRL levels are defined in Appendix D) intended to prove feasibility and then develop and demonstrate computing technologies for eventual introduction into NASA's production and operational scientific computing facilities through entities like NCCS, CoSMO, and EOS. Applications in the areas of Earth and space science, life sciences, and microgravity are used as drivers of ESS computational technology research, providing the requirements context for the work.

ESS performs periodic assessments of technology as it plans major solicitations to meet its Program and Project Level milestones. It also carries out frequent assessments of technology as it adjusts its Task Level milestones.

Based on recent assessments, ESS has designed technology thrusts listed below to carry out during ESS Round-3 (FY 2000-04). They are all expected to mature during Round-3.

- Establish or improve interoperability among related high-performance component codes in model and data analysis software systems; in particular, facilitate the development of a viable Earth System Modeling Framework.
- Develop or improve component codes for use in high-performance model and data analysis software systems.
- Develop high-performance Adaptive Mesh Refinement packages useful to the ESS community.
- Improve the commodity cluster software environment strategically for the benefit of the ESS community.

19. COMMERCIALIZATION

ESS is committed to transferring its technology to the private sector where appropriate.

ESS is currently working with computer system vendors to transfer its extensive experience gained with configuration and operation of powerful clusters of commodity PCs.

Section 6.2 describes how ESS hopes to transition some Round-3 Investigator technologies into effective and timely spin-offs. As part of the Round-3 CAN, ESS has offered proposers the opportunity to:

- Identify ways for making materials and knowledge coming out of their Investigations available to the public or for use in formal and informal education in the U.S.
- Identify ways for making problem solving approaches, algorithms, modules, or data products coming out of their Investigations useful to public organizations such as state and local governments and private industry.

ESS sponsors and conducts technical meetings and workshops and promotes the publication of scientific and technical papers to maintain the flow of technology from NASA to industry and academia.

Commercialization opportunities are exploited through Space Act Agreements, cooperative research agreements, and SBIR contracts with industry.

20. REVIEWS

As part of the HPCC Program, ESS is reviewed annually by an Independent Annual Review (IAR) panel. These reviews are conducted as part of an overall IAR of the HPCC Program and of the other Projects in the program. The IARs are conducted in accordance with established policies and procedures.

A technical review of the ESS Project is conducted annually by the HPCC Program Manager. These reviews are typically conducted at the end of the fiscal year at the Project lead-Center but may additionally involve reviews at supporting centers when convenient. The reviews are conducted to evaluate the progress of the Project and give critical feedback to the Project managers. In addition to appropriate NASA personnel, representatives from other Federal agencies, academia and industry may be invited to participate. Reviews are conducted in accordance with established policies and procedures.

The ESS Project Manager and Associate Project Manager submit monthly reports and present periodic reviews summarizing the technical and administrative performance of the Project. They support the HPCC Program Manager in developing material for quarterly reviews for the lead-Center Director, the Office of Aerospace Technology, and the Headquarters Program Management Council. They also develop the ESS Annual Report for inclusion in the HPCC Program Annual Report. Each member of the ESS Management Team reports status on a monthly basis to the Project Manager

The ESS Project Manager conducts periodic reviews keyed to the accomplishment of specific milestones; they may include requirements reviews, design reviews, software reviews, and readiness or acceptance reviews.

21. TAILORING

This Project Plan conforms to the NASA Program and Project Management Processes and Requirements (NPG 7120.5A), with adaptations appropriate to an ongoing and relatively small activity. Sections on technical summary, controls, performance assurance, and risk management are tailored to the nature of this technology program.

22. CHANGE LOG

1. June 1992, ESS Level-2 Project Plan approved, establishing a 5-year plan for ESS.
2. July 1993, ESS Level-2 Project Plan approved.
3. January 1994, entirely replanned ESS WBS-3.
4. May 1996, ESS Level-2 Project Plan approved.
5. May 1997, ESS Level-2 Project Plan approved.

6. July 1998, ESS Level-2 Project Plan approved. Included 33 new Level-2 milestones in WBS-1, -2, and –3; 11 Level-2 milestones were cancelled. The new milestones were designed to guide the ESS Round-3 activities.
7. June 2000, NPG7120.5A compliant version of ESS Project Plan prepared for approval. It defined the ESS Project for the time frame FY 2000-04.

Appendix A

ABBREVIATION AND ACRONYM LIST

3-D	Three-dimensional
4-D	Four-dimensional
AA	Associate Administrator
AMR	Adaptive Mesh Refinement
ARC	Ames Research Center
AT	Aerospace Technology
CAN	Cooperative Agreement Notice
CAS	Computational Aerospace Sciences
CCIC	Committee on Computing, Information, and Communications
CIC	Computing, Information, and Communications
CICR&D	CIC Research and Development Subcommittee of the CCIC
CoSMO	Consolidated Supercomputing Management Office
CPU	Central Processing Unit
CS	Civil Servant
DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
DOE	Department of Energy
EC	HPCC Program Executive Committee
EOS	Earth Observing System
EPA	Environmental Protection Agency
ESMF	Earth System Modeling Framework
ESS	Earth and Space Sciences
FTE	Full Time Equivalent
FY	Fiscal Year
Gigabits/s	10^9 (1 Billion) Bits Per Second
Gigaflops	10^9 (1 Billion) Floating Point Operations Per Second
GSA	General Services Administration
GSFC	Goddard Space Flight Center
HECCWG	High End Computing and Computation Working Group
HEDS	Human Exploration and Development of Space
HPC	High Performance Computing
HPCC	High Performance Computing and Communications
HPCCP	High Performance Computing and Communications Program
HPREN	High performance research and education network
HQ	Headquarters
HTMT	Hybrid Technology Multi Threaded
I/O	Input/Output
IAR	Independent Annual Review
JPL	Jet Propulsion Laboratory
Level-1	Highest level
Level-2	Second highest level
LTP	Learning Technologies Project
MOU	Memorandum of Understanding
MPI	Message Passing Interface
NASA	National Aeronautics and Space Administration
NCCS	NASA Center for Computational Sciences
NHSE	National HPCC Software Exchange
NIST	National Institute of Standards and Technology

NPD	NASA Policy Directive
NPG	NASA Procedures and Guidelines
NRA	NASA Research Announcement
NRC	National Research Council
NREN	NASA Research & Education Network
NSA	National Security Agency
NSF	National Science Foundation
OMB	Office of Management and Budget
PAPAC	Provide Aerospace Products and Capabilities
PARAMESH	Parallel Mesh Refinement
PBC	Performance Based Contract
PC	Personal Computer
PCA	Program Commitment Agreement
PI	Principal Investigator
PITAC	President's Information Technology Advisory Committee
PMC	Program Management Council
QoS	Quality of Service
R&D	Research and Development
REE	Remote Exploration and Experimentation
RFP	Request for Proposals
RIB	Repository-In-a-Box
Round-1	ESS Investigators in FY 1993-96
Round-2	ESS Investigators in FY 1996-2000
Round-3	ESS Investigators in FY 2000-04
SBIR	Small Business Innovation Research
SEB	Source Evaluation Board
SEWP	Scientific and Engineering Workstation Procurement
SSC	Support Service Contractor
T3E	CRAY T3E distributed memory supercomputer
Teraflops	10^12 (1 Trillion) Floating Point Operations Per Second
TRL	Technology Readiness Level
U.S.	United States
UPN	Unique Project Number
WAN	Wide Area Network
WBS	Work Breakdown Structure
WWW	World Wide Web

Appendix B

ESS Project Background

ESS issued a NASA Research Announcement (NRA) in FY 1992 and a Cooperative Agreement Notice (CAN) in FY 1995 that resulted in selection of Round-1 Grand Challenge Teams funded in FY 1993-96 and Round-2 Grand Challenge Teams funded in FY 1996-2000.

ESS Round-1

In Round-1 (FY 1993-96) ESS engaged 8 critical mass Principal Investigator (PI) Teams of Earth and space scientists, computational scientists, and algorithm designers to make progress toward their proposed Grand Challenge problems using scalable parallel computing platforms. These 8 Teams as well as 21 Guest Computational Investigators (GCIs) were peer selected in early FY93 by NASA Headquarters through NASA Research Announcement NRA-OSSA-92, a joint solicitation between the Office of Space Science (OSS) and what was then the Office of Aeronautics (OA). These Round-1 Investigator teams addressed the following scientific Grand Challenge discipline areas:

- coupled Earth-atmosphere systems science
- Solar coronal and interior physics
- Galactic and cosmological modeling
- Analysis of massive data sets acquired by NASA programs

ESS identified candidate commercial first-generation Testbed systems (1 to10 gigaflops sustained) likely to be scalable to a teraflops or more, acquired four (two were operated at GSFC and two at JPL) Testbeds, and provided Investigators and Project staff access to several more Testbeds at other sites. The GSFC systems were integrated into the NASA Center for Computational Sciences (NCCS) in order to leverage common facilities, support, and experience. T-3 (45 megabits per second) network links were arranged with NREN to interconnect major Testbed sites, and T-1 (1.5 megabits per second) links were arranged to connect the Investigators to the Testbeds.

Science-related performance metrics with baselines were established for the eight Teams. Metrics were updated for the final time in May 1996. The 8 PI Teams and 10 of the GCIs completed work in March 1996. The remaining 11 GCIs completed work in March 1997. Final reports and metrics from the Round-1 PI Teams are posted at:

http://esdcd.gsfc.nasa.gov/ESS/sciteam1.report/sciteam1.gc.html

ESS Round-2

In Round-2 (FY 1996-2000) 9 Grand Challenge Investigator Teams and a Testbed vendor were acquired through a single Cooperative Agreement Notice (CAN-21425/041). The resulting Cooperative Agreements were structured to use negotiated milestone payments to incentivize strong collaboration between the Testbed vendor and the Investigators to meet aggressive ESS performance milestones of 10, 50, and 100 gigaflops (or 200-fold improvement over 1992 baseline) sustained on specific Investigator codes. Descriptions of these Teams and their achievements can be seen at:

http://esdcd.gsfc.nasa.gov/ESS/annual.reports/ess98/ess98.html

The CAN was released in May 1995, proposals were received in August 1995, and a full peer review was carried out for the Investigator proposals. All ten Cooperative Agreements had been signed by the fall of 1996. All Cooperative Agreements between GSFC and Investigator institutions (worth $12.6M in total) are worded identically, and a sample is available at http://esdcd.gsfc.nasa.gov/ESS/can.invagree.html. The Cooperative Agreement between GSFC and SGI/Cray was worth $13.2M. All Cooperative Agreements will have ended by the end of June 2000.

All codes that achieved performance milestones were required to be documented and released to the science community on the Web through the ESS software repository, a branch of the National HPCC Software Exchange (NHSE). The Cooperative Agreement with SGI/Cray included placement of a large scalable parallel Testbed at GSFC, primarily to support the research needs of the Round-2 Investigators by sustaining 25 to 50 gigaflops on their codes, but also to assist in transitioning the broader NASA science community to parallel computing through a Guest Investigator Program and to support research of the HPCC Computational Aerosciences (CAS) Project. The Round-2 Testbed was integrated into the NCCS facilities. Facilities had been constructed during FY 1994 to house this Testbed along with a Guest Investigator Facility to accommodate researchers from Round-2 Teams who wished to spend time at GSFC working directly with the ESS staff and using high-performance visualization equipment.

Through milestone payments in the ESS Cooperative Agreements, the participating Testbed vendor's success criteria were linked directly to the Investigator Teams' performance, which were in turn linked to the HPCC PCA milestones. All payments under the Round-2 Cooperative Agreements were tied to the achievement of milestones. There are 117 negotiated milestones worth a total of $25,803,000. The Investigator Teams and the Testbed vendor were thus brought in as equal partners with NASA staff in achieving the project milestones, resulting in excellent cooperation and collaboration among the Project staff, Grand Challenge Investigators, and the Testbed vendor. A table of all Investigator and vendor milestones is at http://esdcd.gsfc.nasa.gov/ESS/can.milestones.html; these were Level-3 milestones in the NASA HPCC Program. In early 1998, the Round-2 Investigators projected their computing, storage, and data movement requirements for low-, medium- and preferred-resolution models. This information is presented below in Table B-1.

In April 1998, the ESS T3E was doubled in size from 512 to 1,024 processors to support the NASA Seasonal to Interannual Prediction Project (NSIPP), one of the highest priorities in the Strategic Plan of the Earth Science Enterprise, producing a system ranked in the top 5 supercomputing platforms worldwide. In early 2000, NSIPP received dedicated use of 1,024 processors. These upgrades were justified based on NSIPP climate codes developed during ESS Round-1 and scaled up under Round-2 Guest Investigator allocations of T3E time.

As of February 2000, 8 ESS Round-2 Grand Challenge Teams had achieved 50 gigaflop/s sustained performance on their code(s) as negotiated, 7 had submitted documented versions of these codes to the NHSE, 7 had achieved 100 gigaflops sustained, and 5 had submitted versions of these codes to the NHSE.

Table B-1: ESS Round-2 Investigator Requirements (2/98)

Team PI:	Olson	Curkendall	Mechoso	Lyster	Carey	Malagoli	Gardner	Gombosi	Saylor

Group-1: LOWER RESOLUTION MODEL

Name of model:	TERRA	SAR	UCLA Earth System Model	GEOS-2 DAS Current	MGF-L	Phi3D	FCT MHD3D	BATS-R-US	NS128
Main Memory size (gigabytes)	2.5	32	16	2	64	1	4	10	4
"Disk" size (gigabytes)	10	4	2	8	40	20	24	2	12
Mass Storage size (gigabytes)	100	4	250	2,270	400	100	200	4	120
Volume of data to be transferred via network from 'model run' at GSFC to Investigator local environment (Gbytes)	0.1	4	2-5	-	4	100	8	2	120
Gigaflops sustained	10	50	10	0.25	50	50	50	60	55
Duration of run (hours)	3	.05	200	8,760 (1 year)	4	500	60	4	6

Group-2: MEDIUM RESOLUTION MODEL

Name of model:	TERRA	SAR	UCLA Earth System Model	GEOS-2 DAS 1999	MGF-M	MPS3D	FCT MHD3D	BATS-R-US	2NSmed
Main Memory size (gigabytes)	20	64	64	2	256	24	15	50	32
"Disk" size (gigabytes)	80	20	10	47	160	100	90	10	100
Mass Storage size (gigabytes)	800	200	1,000	13,265	1,600	7,500	1,000	40	800
Volume of data to be transferred via network from 'model run' at GSFC to Investigator local environment (Gbytes)	1	200	5-50	-	16	1,000	30	10	600
Gigaflops sustained	40	100	40-50	6	100	100	100	60	100
Duration of run (hours)	12	2.5	200	8,760 (1 year)	6	1,000	120	20	60

Group-3: PREFERRED RESOLUTION MODEL

Name of model:	TERRA	SAR real-time *	UCLA Earth System Model	GEOS-2 DAS 2000	MGF-P	MPS3D	FCT MHD3D	BATS-R-US	2NSpro
Main Memory size (gigabytes)	160	128	256-512	6	1,000	110	120	120	256
"Disk" size (gigabytes)	640	64	50-100	225	640	1,000	720	40	1,000

Mass Storage size (gigabytes)	6,400	480	6,000-7,000	74,218	6,400	60,000	8,000	80	3,000
Volume of data to be transferred via network from 'model run' at GSFC to Investigator local environment (Gbytes)	10	480	25-100	-	64	10,000	240	40	3,000
Gigaflops sustained	320	250	500-1,000	44	1,000	500	200	120	2,000
Duration of run (hours)	24	1	200	8,760 (1 year)	4	1,500	480	100	120

* (SAR data takes are 15seconds, so real-time here means processing 240 15-second scenes in 1hour). In order for the data from a mission to be processed one would really need to use the total size of the mission data collected for the mass storage question and the volume of data across the network, but 1 hour is used here for starters. Note: to maintain the data flow, the required network bandwidth is on the order of OC-12.

Appendix C

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Appendix D

Technology Readiness Levels (TRL) as Defined by NASA

NASA's research activities are categorized by a system that assigns numerical values to levels of technology maturity ranging from basic research to production ready.